The Effects of an Integrated Space Support Node
on Theater Air Combat

THESIS

Paul J. Helt
Captain, USAF

AFIT/GSO/ENS/93D-10

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THE EFFECTS OF AN INTEGRATED SPACE SUPPORT NODE ON THEATER AIR COMBAT

THESIS

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of the Air Force Institute of Technology

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Paul J. Helt, B.S.

Captain, USAF

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COMMITTEE:	NAME/DEPARTMENT	SIGNATURE
ADVISOR	Colonel Gregory S. Parnell Head of Operational Sciences Department	G Parnell
READER	Maj Lee J. Lehmkuhl Assistant Professor of Operations Research Department of Operational Sciences	Lee J. Lehmkuhl
READER	Joseph P. Cain, PhD Assistant Professor of Economics Department of Operational Sciences	Joseph P. Cain

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Paul J. Helt

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Abstract

The Air Force requires a methodology to assess alternative means for providing integrated space support data, collected from imagery space platforms, to enhance overall theater warfighting capability. This research examines imagery systems supporting the warning, surveillance, and weather missions, alternative concepts to integrate this imagery data, and models their influence on air-to-ground and limited ground-to-air combat in five potential theaters of operation. These theaters were Northeast Asia, Southeast Asia, Southeast Europe, the Carribean, and Central America. Influence diagram decision analysis techniques were used to identify and quantify the key variables within the three space-based mission areas effecting air combat planning and execution. The theater warfighter's imagery requirements and air campaign planning theory were examined and linked to identify the affected air combat measures of effectiveness. The results of this research and air combat simulation reveals a significant increase in sortie effectiveness and lethality by incorporating space based imagery support into theater conflict through acquiring and deploying an integrated space support center. The methodology provided can be tailored to include any number of theaters of conflict and modified to study other military space systems.

Chapter 1 - Introduction

> Speed is the essence of war. Take advantage of the enemy's unpreparedness; travel by unexpected routes and strike him where he has taken no precautions. The doctrine of war is to *follow the enemy situation* in order to decide on battle [emphasis added, 16:134,140].

1.1 Background. The US military is adopting a strategic focus on regional contingencies. The basic official document of US military strategy today is *National Military Strategy of the United States*, which emphasizes the need for US military strategists and planners to account for regional threats to the United States [42]. As the 1991 Persian Gulf War attests, regional conflict has come to the forefront of the American military. According to Motley and Mazarr, two respected strategic analysts, the military forces of the United States must prepare for conventional, theater level conflict [41 and 39]. Mazarr asserts the United States should expect "certain forms of conflict between counterinsurgency and major war...posing the key challenges to U. S. interests, and hence [military] planning, into the twenty-first century [38:3]." The general trend of US military strategy and planning is toward involvement in a theater level war. Accepting this reality, US forces need to be more mobile and flexible to react in a short time to anything, anywhere, at any time. The space community has a responsibility to support the theater warfighter.

The Gulf War was indeed a "space-age" war with unprecedented use of satellites [13:241]. Many authorities examined space based systems' benefits in the war, as well as their limitations. Common limiting factors were found in all space based mission areas: warning, communications, surveillance and reconnaissance, weather, and navigation. First, the military lacked planning for space support to theater-level war. "The Pentagon rushed to equip the troops with space-related ground equipment [30:36]" and data: Defense Satellite Communications System terminals for communication; Defense Support Program communications gear to get Scud launch warning data to Patriot batteries defending Israeli and Saudi Arabian cities, Defense Meteorological Support Program terminals to get weather and terrain data into planning cells, Global Positioning System receivers for positional fixes and precision guided munitions (PGMs), and hard copy

imagery data for mission planning and execution. Second, there was no established network or connectivity infrastructure for disseminating space based data into the theater conflict. Third, no cohesive command structure existed at the theater level to control any of the space mission areas, let alone to control the independent and often redundant quick fixes made by system-specific space personnel to get space data into the theater.

Each of these Gulf War problems was a symptom of the space community's lack of preparation for theater level conflict. When General Charles Horner, the Air component commander in the Gulf War, took command of US and AF Space Commands, he directed, "What we have to do is change our emphasis from strategic war to theater war. All of us in the space community must concentrate our thinking on how we can directly support the warfighters [4:30-34]." In response to the lessons from the Gulf War and Horner's mandate, Space Command formed the Space Warfare Center (SWC), focusing on developing a central fusion node for collecting, processing, and integrating space based data from all satellite systems supporting the mission areas listed before. A central node directly linked with the Defense Support Program (DSP), for instance, would provide the theater CINC accurate and timely missile launch data for distribution to shooters such as Patriot batteries and aircraft flying combat air patrols. This integration center should also be directly linked into the theater CINCs combat execution and planning centers. A node of this calibre provides information for theater missile defense under space's warning mission; imagery, mapping and battle damage assessment for combat mission planning and execution under the surveillance and reconnaissance mission; satellite communications under the communications mission; and terrain and atmospheric analysis capability through the weather mission.

The Persian Gulf war is "the first war in which space systems had a decisive role [13:241]." Although the United States' national use of space has been predominately strategic in nature over the past forty years, there is an increasing trend in space toward preparation for regional, theater warfare. The strategic mission for space has not disappeared, but theater use of space is gaining in importance. The major lesson learned during the Gulf War is the need for consolidated, timely, and responsive space based data fed directly into theater operations planning [13].

Two concepts for providing space data to the theater need to be examined. The first is a fixed node based within the continental US, and the second is a transportable node deployed within the theater of operations.

1.2 Problem Statement. The Air Force requires a methodology to assess alternative means for providing integrated space support data, collected from space platforms, to enhance overall theater warfighting capability.

1.3 Research Scope and Objectives. The primary objective of this thesis is to analyze alternative integrated space support center locations in order to find the most effective system to place space data into theater level campaign planning and warfare execution. A secondary objective is to evaluate the cost effectiveness of the fusion node alternatives. The magnitude of this effort dictates a restricted scope. This thesis will be limited to evaluating the differences between systems located within the continental US and those deployed into the South West Asian, the Middle Eastern, and the Korean Peninsula theaters of operations. Research will assess effects of alternative fusion nodes integrating current warning, weather, remote sensing, and communications systems on air combat. The specific systems included for each space mission area are:

a. Warning: Defense Support Program (DSP)

b. Remote Sensing: Landsat and System Pour L'Observation de la Terre (SPOT)

c. Weather: Defense Meteorological Support Program (DMSP), National Oceanic and Atmospheric adiministration (NOAA), and Geostationary Operational Environmental Satellite (GOES)

1.4 Use of Decision Analysis and Thesis Methodology. The analytical design for this effort will use decision analysis techniques. Decision analysis is the study of modeling complex, multi-objective decisions including uncertainty and preferences [7]. An influence diagram model of the thesis is given in Figure 1.1.

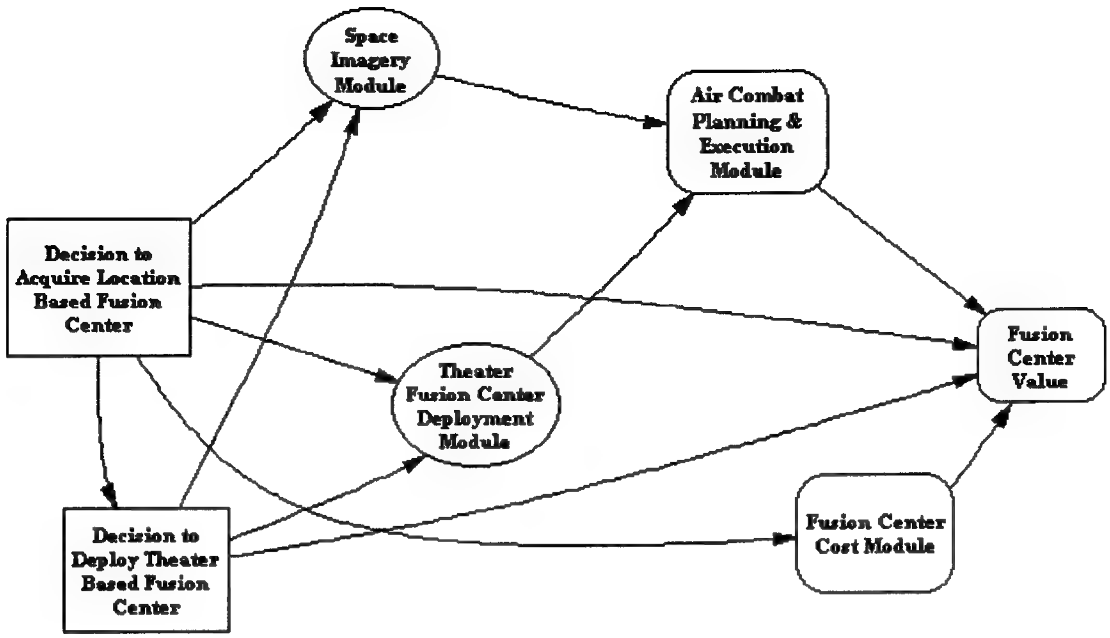


Figure 1.1: Model for Analyzing Space Imagery Infusion into Theater Operations.

Decision analysis modeling, influence and tornado diagrams, and decision and value trees were used to generate a quantitative air combat measure of effectiveness to compare the integrated space support (ISS) center alternatives. The model in Figure 1.1 required extensive research to develop. The bibliography provides the research sources. Telephone and personal interviews were also used to obtain realistic data to build the model. The simulation was evaluated using Decision Programming Language (DPL) decision analysis software. Simulation runs, bolstered by the data collected and probability distributions developed from warfighting sources, generated data to conduct analysis on the air combat measures of effectiveness for each of the integrated space support center location alternatives. The final stage of this study involves validating the model, then evaluating and documenting the results using decision analysis techniques studied.

Chapter 2 - Modeling the Combat Contribution of Satellite Imagery Systems

2.1 Background on Modeled Imagery Space Systems

> Today's mobile targets, though less potent than old Soviet ICBMs SRTs [strategically relocatable targets], are even more difficult to detect. During the Gulf War, the Air Force was frustrated in its effort to pin down Iraqi Scud launchers. The problem is that medium-range missiles have inherently greater mobility than do larger strategic weapons. Road-mobile SS-25s and rail-based SS-24s had more limited deployment areas; consequently, less terrain had to be searched. Scud decoys are easier to build. In addition, when it came to identifying Scud launches and alerting coalition troops, the Air Force found the existing strategic warning system — the Defense Support Program (DSP) satellite system — ill-suited for the demands of a theater campaign. The Air Force acknowledges that it was unable to pass DSP satellite targeting information directly to the fighters flying Scud combat air patrols. The system often provided multiple, uncorrelated warnings of a launch. The Air Force called the configuration *ad hoc*, saying it provided neither timeliness nor the required accuracy [35: 68].

2.1.1 Warning Segment. Under the Defense Support Program (DSP), the military operates several satellites in geosynchronous orbit for detecting the hot exhaust plumes of ballistic missiles during the early stages of their flight. DSP passes strategic warning information directly to two large processing ground stations located at Nurrungar, Australia, and Buckley Air National Guard Base (ANGB) near Denver, CO, or to a simplified processing station in Europe. The data is then relayed via the space based Defense Satellite Communications System (DSCS) to the Data Distribution Center (DDC) at Buckley for transmittal to appropriate authority [52:25].

"Early warning space systems proved critically important [17:181]" during Desert Storm in keeping Israel out of the war when Iraq began launching Scud missiles at Israeli cities. DSP would detect a tactical ballistic missile launch during its boost phase and pass the information on to Central Command headquarters in Saudi Arabia through it's ground control network. This critical early warning data was crucial in locating Iraqi launch vehicles as well as alerting ground forces near and around the projected impact point of the approaching missile. Patriot batteries and other defensive measures could be prepared and have a better chance negating the Scud before any damage occurs. Aircraft flying in Scud CAPs (Combat Air Patrols) were directed toward the Scud's launch point in

an attempt to kill the launcher using data derived from DSP [17:181-182]. During Desert Storm DSP performed imperfectly. The DSP satellites "...were originally intended to detect the launching of Soviet [now CIS] ballistic missiles, [a strategic mission]. During the Persian Gulf War, two DSPs could generally locate a Scud launch plume within 120 seconds of firing. Location was not nearly precise enough to engage the missile directly, but it was enough to alert the targets and the Patriot missiles protecting them. The entire system [to fight the Scuds (satellites, communications, and ground based missiles)] was a crude version of the projected strategic defensive system, [the original DSP concept][13:241]."

The warning arrangement was put together rather quickly for Desert Storm affecting timeliness and accuracy of the warning data. Improvements in collecting and distributing DSP data are needed. The dated DSP strategic architecture, involving a small number of ground stations passing warning manually to commanders in the field, must be changed to a system in which data is delivered to users automatically, perhaps directly from satellites [56:153]. The timeliness of DSP launch detection was key in Desert Storm. Iraqi Scud teams could launch a missile, drive away, and hide under cover in less than five minutes [17:183]. Raw launch data from DSP was downlinked to ground processing centers and routed to the central DDC at Buckley before being sent to Central Command's headquarters in Saudi Arabia, costing precious time. Aircraft in Scud CAPs usually did not get launch point data in time to knock out Scud launchers, but Patriot batteries did get the data in time to defend against the Scuds themselves. The two key problems found were the timely collection, including accurate processing, and dissemination of tactical ballistic missile launch data — launch location and impact point — to the warfighter. Lieutenant General Thomas Moorman, Air Force Space Command Commander, said of this situation, "space officials were unable to respond as quickly as needed because of the lack of advance planning and need to work on integrating space into operations plans [56:71]." The overall problem was the space warning mission infrastructure at theater level did not exist before Desert Storm.

2.1.2 Surveillance Segment. There are really three facets where surveillance imagery is important to the theater commander. First, surveillance imagery is needed during planning to identify appropriate targets, to identify target vulnerabilities, and to

select optimum routes to the target. Second, imagery is required during mission execution for visual target recognition by the attack force. Last, surveillance imagery is required after mission execution to determine accurate battle damage assessment (BDA), the analytical examination of targets struck to determine the amount of damage they sustained [56:75]. Timely and accurate BDA is essential to theater air combat primarily because the knowledge of which targets are destroyed and which are still active determines the future allocation of strike packages. Also, BDA provides a quantitative assessment on how well an air campaign is progressing and how far along the campaign is in attaining its objectives.

The key problem in this mission area is the lack of any deployed Department of Defense (DoD) surveillance or imagery platforms. Space based radar is in concept development with an operationally deployment date well after 2015. Multispectral imagery is much farther along with actual deployed systems in existence, namely Landsat and SPOT (System Pour L'Observation de la Terre). Unfortunately, neither of these systems is devoted to military missions. Landsat is an aging satellite system under Department of Commerce (DoC) control whereas SPOT is more modern, but French owned.

During Desert Storm, the DoD made an agreement with the DoC and SPOT Image Corporation through the Defense Mapping Agency (DMA) to improve the process of obtaining imagery data from Landsat and SPOT in a timely manner. DoC and SPOT Image handled DoD and DMA imagery requests at a higher priority since no new images were available of the Persian Gulf theater of operations to build current maps. Also, data dissemination of the imagery was speeded up to two to three days in delivery time. SPOT corporation imagery was used extensively because of their higher resolution, but only when the importance of the imagery products was greater than their cost. SPOT imagery was not available to Iraq since France restricted imagery dissemination to only allied forces in the war [13:240]. In Desert Storm, "at the top of list of disappointments [was] intelligence timeliness and distribution despite the availability of imaging systems and technology." The institutionalized imagery process — the systematic acquisition, analysis, and distribution of imagery — was unsatisfactory. Mainly, the tasking channels, timeliness

of response, and resultant dissemination of imagery for use in mission planning to BDA was "cumbersome" [17:244]. Landsat imagery data from the Earth Observation Satellite Corporation (EOSAT), for instance, was usually sent to CENTCOM planners in Saudi Arabia via the Tactical Digital Facsimile (TDF). The TDF "furnished the only secure means of updating target folders" during the opening days of Desert Storm [17:308-309]. Imagery timeliness also effected other important areas of mission planning, especially BDA. The "BDA timeliness and quality did not allow full exploitation of US target acquisition and attack capabilities. Accurate BDA reports are necessary for effective military operations: they serve as a force multiplier, allowing military commanders to focus successive attacks on the most important remaining targets. The problem was that timely information was not always available [and] not enough thought had been given to presenting real time BDA data to operational commanders and staff planners [39:106]." Satellites used for BDA were also limited by their orbits because "they passed over the target areas at set times. If that was too many hours after the strike, the Iraqis had time to simulate bomb damage in hopes of avoiding a later attack [13:186-187]." Improved timeliness and data distribution, higher resolution, and a better process for use of imagery products are needed at the theater level.

Once again, the infrastructure to provide theater level warfighters necessary surveillance data was lacking during Desert Storm. These imagery specialists did their work independent of those trying to establish better warning in the Desert Storm theater, duplicating much of the communications connectivity to Saudi Arabia [17; 55].

2.1.3 Weather Segment. Weather imagery is used for route and weapon selection, determining terrain and atmospheric conditions of the battlefield and over targets, and detecting solar activity effecting radio communications throughout the theater of operations. Information collected is used in forecasts provided to combat mission planners to support them in making decisions pertaining to the theater air campaign.

During Desert Storm, with weather in the Gulf "the worst in fourteen years, the Defense Meteorological Satellite Program (DMSP) played a critical role in supporting mission planning, as well as being the first system to spot [Iraq's] use of eco-terrorism" in igniting Kuwait's oil fields [44:1]. DMSP extensively supported the mission planning

needs of the theater commander during the war. DMSP was used to support mission planning by providing wind direction and velocity, smoke, haze, fog, and cloud cover affecting weapons choices, aircraft loads, and mission profiles. DMSP detected ground texture affecting the ability to move troops, tanks and trucks, and to fly missions [44:1]. The only problem noticed during the war related to space's weather mission was the timeliness of the data disseminated to the theater. Raw data had to first go through CONUS processing before reaching CENTCOM in Saudi Arabia, causing dissemination delays [17]. Space's weather mission provides information essential to the theater commander which must be maintained and integrated with other forms of space related data from warning and surveillance platforms.

2.2 *Background on the Space Based Imagery Integration Center Concepts*

> Historically, space planning has tended to focus on individual missions — communications, navigation, weather, etc. — and their individual roles or contributions to specific military operations [27].

Chapter one addressed the common limitations found in all space based mission areas. First, there was the lack of planning for space support to theater level war; second, no established communications infrastructure for disseminating space support data into the theater conflict existed; and third, no cohesive command structure was established at the theater level to control any of these mission areas. The space community has a long history of reacting to problems by "charging off in many directions at once without good centralized planning [58:29]." This basic problem is what can be described as decentralized control, centralized execution at the theater level. The dispersion of technologies devoted to particular mission areas without regard to military operational concepts of standardization and control was apparent when space officers went over to the Persian Gulf to work command and control and data dissemination issues for each of their individual space systems.

The theater commander needs a space operations staff with a space component commander providing a central node to collect, process, fuse, and integrate all space based data from all mission areas. This theater node directly linked with DSP would provide the

theater CINC accurate and timely data for distribution to shooters like the Patriot batteries and aircraft flying Scud CAPs. A theater node could provide selective denial of GPS, manage the communications channels of DSCS, direct contact today's Landsat archives, and any future multispectral imagery data, and serve as a downlink processing terminal for DMSP, NOAA, and GOES as well as DSP and Landsat. The node could also be given tasking functions for certain DoD surveillance and reconnaissance satellites. Unity of command must apply to space based assets in the theater environment to fuse and integrate all space data for the theater CINCs use. The node must be directly tied into the theater CINCs combat execution and planning centers. One of the basic tenets in US Air Force space operations doctrine is to provide "centralized and automated centers" located "in theater to fuse all data from national systems, satellites, and other assets and intelligence sources" to be "exploited by all component commanders simultaneously to meet their needs [27:30]." A space component commander would be needed to direct the use of limited space based theater level resources and provide unity of command for space power. Finally, to be effectively exploited, this center should be close to the air, ground, or naval campaign planning cells — in theater. Integrated Space Support (ISS) within theater can fuse space based sensors into a common command and control node to improve raw data processing, timeliness of data dissemination, and connectivity between the space community and the theater warfighter. Some day, this may be the norm for theater level space operations, but there is long way before this goal "to better exploit the capabilities of our current [space] systems to support air, land, and naval operations" at the theater level can be met [27:10].

2.2.1 Integration Center Alternatives.

2.2.1.1 Talon Shield/Attack and Launch Early Reporting to Theater (ALERT). Today, AF Space Command is responding to the problems posed by Desert Storm to theater warning with a prototype demonstration called Talon Shield. This prototype, located in the Central Tactical Processing Element (CTPE) at Falcon AFB, CO, will fuse national system data with DSP to allow high-confidence assessment of the

validity of DSP infrared indications. Talon Shield processes DSP downlinked data in a separate environment from the DSP strategic mission to support theater commanders with information on theater missile activity. Warning information will be disseminated on existing theater networks. The system will detect and notify theater forces of theater ballistic missile boosters, fixed and mobile launch sites, and static infrared events [36:1]. Here again, mission specific personnel have come up with a fix to the theater warning mission problem. The key here is Talon Shield, at present, only concentrates on theater missile warning, not any of the other mission problems found during Desert Storm. The Talon Shield program will determine the changes needed to maximize tactical performance of present or near term sensors, data processing, and communications systems in the missile warning mission area. The general philosophy is to improve existing systems first and to develop new systems when upgrades to existing systems cannot support the Theater Missile Defense (TMD) mission requirements.

> To boost US theater missile defense capability, the SWC [Space Warfare Center] is pursuing Talon Shield, a program aimed at fusing satellite intelligence with DSP readings of a missile's telltale infrared emissions. A prototype central processor — maintained at the National Test Facility (NTF), collocated with the SWC in Colorado — receives tactical incoming DSP warnings on a channel separate from that used to relay data from the strategic warning system. Talon Shield will send warnings of theater missile launches to commanders in the field. The messages will include data on when and where the launch originated, its indicated target, and its expected impact time. The existing prototype operates at the NTF eight to twelve hours each day and can support only one theater at a time. The Air Force plans to expand that capability to a twenty-four-hour watch for two theaters beginning in Fiscal 1995. Talon Shield is designed to use existing theater commmunication networks. Air Force plans call for an October 1 activation of the Talon Shield system under a new name, ALERT [35:69].

Talon Shield will enhance the ability to detect, locate, and identify tactical missiles and supporting infrastructure by improving the ability to collect, process, exploit, and correlate all source intelligence and sensor data, providing this information to theater forces in under 90 seconds from event initiation to final, valid warning message dissemination to user, and integrating space missile warning systems into theater operations.

2.2.1.2 Transportable Theater Center Alternatives.

2.2.1.2.1 SHADOW Project. SHADOW was a conceptual study sponsored by the Combat Support Division within the Force Enhancement Directorate of Air Force Space Command (AFSPC). Working with the DSP System Program Office, AFSPC developed SHADOW to demonstrate and exercise the integration of advanced space based sensors into a theater deployable and transportable center to improve data collection, processing, and dissemination timeliness and responsiveness. The system was to provide increased warfighting effectiveness by linking the theater battle commander to space by downlinking space assets directly to the theater commander's decision level. SHADOW was to provide a rapid and timely delivery method for battlefield information and commands throughout all elements of the theater.

The unique feature of SHADOW was it's communications architecture, Figure 2.1.

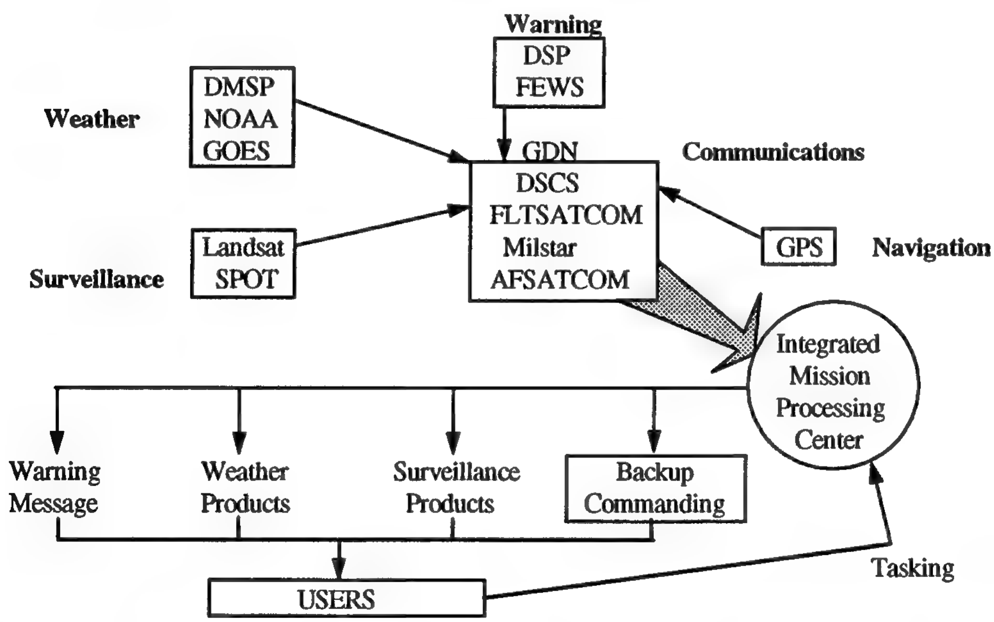


Figure 2.1: Integrated mission processing center (IMPC) operational concept [21].

SHADOW was to consist of globally distributed and interconnected up- and downlink data preprocessing relay antennas and what is called the global data network (GDN). Information from all space based assets, including national, would be collected, processed, pooled, updated, and made available globally via simple PC terminals. Operators were to login into the GDN

and call up data via specific mission areas — warning, weather, and surveillance. This would be accomplished through state-of-the-art hardware and modular, mission unique software. The operators would be able to go from one mission to another by simply selecting the approriate software menu.

SHADOW was designed to collect theater-wide missile warning; weather data on a common time and reference grid combining DMSP and GPS; and theater-wide surveillance capability from SPOT and Landsat. Weather capability would include DMSP, NOAA, and GOES. SHADOW's architecture, Figure 2.1, could provide global connectivity for multiple satellite systems. The system's integrated mission data includes, but is not limited to, an overlay of imagery and radar surveillance; DSP warning; and DMSP, NOAA, and GOES integrated weather data. SHADOW's integrated capabilities include communications management and mission processing. The processing will be at the theater commanders' decision level, enhancing the warfighters' overall mission planning and execution effectiveness. SHADOW was to provide a three-dimensional view of the battlefield for effective mission planning and permit real time changes to mission execution [21].

2.2.1.2.2 Integrated Space Support (ISS) System. The Integrated Space System (ISS) is another conceptual design — developed by the 94-D graduate class in space operations at the Air Force Institute of Technology (AFIT) — to provide theater commanders a central node for streamlined control of space platforms and payload functions. First, ISS would give the theater commander rapid input into the tasking of selected space based platforms. Secondly, ISS would be the center through which data from these systems is received, processed, and disseminated. Consolidating these functions in the ISS gives the theater commander unprecedented access to space.

Integrating selected information from the three space-based disciplines gives a theater commander the maximum benefit of space data. A synergy is created: the net result is more powerful than the sum of its parts because information from one perspective builds on data from other disciplines. Knowledge from one source clarifies and multiplies knowledge from a different source. Since no efficient system exists which can guarantee

information in a timely manner, nor one which allows the theater commander to directly task satellite information-gathering, a single module must be created which can integrate space-based weather, early warning, reconnaissance, and surveillance assets. The system must be as transportable as the unit it supports, namely the theater commander. The system will include integrated tasking and data reception equipment of selected space-based assets. Lastly, the system will act as a short-term archive in order to hasten data dissemination to unit commanders. The node could be contained within a 24-foot van similar to a Patriot command vehicle [1].

2.2.1.2.3 Multisource Tactical System (MSTS). The MSTS is an actual prototype providing imagery intelligence updates for aircrews en route to targets. The system has been demonstrated on C-141, C-130, and KC-135 aircraft on relief missions over Bosnia-Hercegovina. The system "provides [archived] multispectral imagery from Landsat or SPOT satellites; digital charts and elevation maps; satellite intelligence (including signals intelligence) on air- and groundbased threats; and real-time location data from the Global Positioning System [14:70]." MSTS is intended to provide intelligence information to both aircrews and troop commanders riding along in the rear of aircraft. In-flight updates can be provided by the existing Tactical Information Broadcast System (TIBS) of a nearby E-3 Airborne Warning and Control System (AWACS) aircraft. The most recent MSTS version is compact — the unit has a twelve-inch computer monitor — and fits into a C-130's navigation station, taking twenty minutes to install, and requiring only one operator. Further work will concentrate on graphic interfaces and provisions for receiving weather updates from DMSP.

2.2.1.2.3 EAGLE VISION Demonstration. EAGLE VISION is a proposed demonstration to receive and process SPOT and Landsat 6 imagery. The demonstration is planned to start the second quarter of FY94 and last through FY95. If warranted and approved, full scale production, acquisition, and integration of EAGLE VISION into a deployable imagery processing system will begin immediately.

2.2.2 Integration Center Assumptions.

1. The CONUS based integration center is 100 percent functional.
2. The least expensive center is a theater based system.
3. All integration centers have adequate communications connectivity to the theater.
4. Logistical support and deployment of a theater node has high priority.
5. A CONUS center has more satellite processing capability than a theater center.
6. A CONUS center has more human analyst capability than a theater center.
7. A theater center has a better perspective on theater imagery requirements.
8. A theater center imagery dissemination is more timely and responsive.

2.3 Imagery Simulation (IMSIM) Development. The three basic, space based imagery mission areas examined were warning, surveillance, and weather. This section will outline what imagery is needed for air combat planning and execution, how imagery is used, and in what way does imagery effect actual air combat in a theater of operations.

2.3.1 Warfighter Requirements. Table 2.1 summarizes the specific forms of imagery required by planners and it's expected use. The material listed in the table was collected from several satellite system operational requirements documents (ORDs).

Table 2.1		*Form of Imagery Data*	*Data Utility*
Space Missions	Warning IR Imagery	Missile launch IR signatures	Locate enemy launch platforms Alert ABM batteries Alert ground forces Defend against missile attack Alert combat air patrols Attack launch platforms
		Aircraft afterburner IR signatures	Intercept enemy aircraft Alert ground forces Alert combat air patrols

Table 2.1 (cont.)		*Form of Imagery Data*	*Data Utility*
Space Missions	Surveillance Imagery	Images of targets for target folders	Tactical mission planning Target selection Optimal route selection Weapons delivery planning Optimal weapons selection Perspective scene generation
		Battle Damage Assessment	Tactical mission planning Target selection Weapons delivery planning Optimal weapons selection
		Detect enemy vehicle movement	Tactical mission planning
		Detect enemy formation movement	Tactical mission planning
		Terrain and vegetation assessment	Tactical mission planning Optimal route selection Updates to aeronautical charts Terrain mapping and topography
		Camouflage, concealment, and deception detection	Tactical mission planning Target selection Weapons delivery planning Optimal weapons selection
	Weather Imagery	Weather forecasts over targets	Tactical mission planning Target selection Optimum route selection Weapons delivery planning Optimum weapons selection Updates to aeronautical charts
		Terrain assessment	Updates to aeronautical charts Terrain mapping and topography Perspective scene generation
		Atmospheric conditions	Tactical mission planning Target selection Optimum route selection Weapons delivery planning Optimum weapons selection Updates to aeronautical charts
		Cloud cover	Tactical mission planning Target selection Optimum route selection Weapons delivery planning Optimum weapons selection Updates to aeronautical charts
		Oceanographic conditions	Tactical mission planning Optimum route selection Weapons delivery planning Optimum weapons selection Updates to aeronautical charts
		Solar events and effects	Tactical mission planning Updates to aeronautical charts Determine communications effects

[19:1-2; 20; 21; 22:8; 25; 27:24; 28; 32; 34; 46; and 47]

2.3.2 Methodology. Table 2.1 identifies the imagery needed and used by theater air campaign planners. Modeling these requirements, along with the lessons learned about how imagery was used during the Gulf War, encompasses this entire thesis effort. From

the discussion about space based imagery's limitations during the war, there were three common factors in the warning, surveillance, and weather mission areas found. In short, these factors dealt with 1) command and control of the space based assets and information derived from them; 2) responsive access to space derived imagery and space based platforms; and 3) the timely dissemination of the imagery once it's obtained. The research, modeling, and analysis done in this thesis was to determine whether acquiring an imagery integration center will improve warfighting capability. Next, the work was to find out how it will effect the theater warfighter's operational effectiveness.

From examining documentation from the Gulf War, an ISS will certainly take care of unity of command — the first common factor listed above. An ISS will also improve responsiveness and timeliness of imagery obtained from space based platforms — items two and three above. The question is, will acquiring a theater, CONUS, or both a theater and CONUS center improve theater warfighting effectiveness? Developing a model encompassing the attributes of imagery as listed in Table 2.1 and relating them to an air combat model was essential in answering this last question.

After evaluating how space fared during the Gulf War, an examination of the attributes of space based imagery relative to warfighters' operational needs was done on each of the three individual mission areas. Under theater ballistic missile launch warning, the speed and accuracy of IR imagery was determined to be essential [17; 53]. Two attributes emerged for the model, namely impact point prediction accuracy and launch point prediction time. With respect to surveillance, the quality of imagery and its timely distribution to theater warfighters was important, relative to mission planning and battle damage assessment [8; 17]. Three characteristics were defined under this mission area, being surveillance imagery credibility, resolution, and imagery assessment reliability. Finally, the weather mission area simply requires timely distribution of high quality data [17; 53]. Two items were concluded to model this imagery: weather data timeliness and imagery quality.

The attributes developed for modeling imagery are defined in detail in chapter 3 and are the main areas of value to planners. Relating this knowledge to air combat in a clear and viable manner was the next challenge in this study.

2.3.3 Modification to GPS Tactical Air Combat Simulation Model (TACSIM). How the imagery characteristics effect air combat requires development of a second model. During the effort to build this combat model, research concentrated on understanding the planning and execution of theater air campaigns. The air combat missions offensive and defensive air superiority, interdiction, and close air support and their respective priorities within a theater campaign were studied as a basis to develop an initial combat model.

Air superiority "...means having sufficient control of the air to make air attacks --- manned or unmanned --- on the enemy without serious opposition and, on the other hand, to be free from the danger of serious enemy air incursions [55:10]," including air-to-air engagements, hitting enemy airfields, theater command and control systems, radars, and other ground based defenses. *Theater* air superiority, or supremacy, "means friendly air can operate any place within the entire combat theater [55:11]."

Interdiction is "any operation designed to slow or inhibit the flow of men or materiel from their source to the front, or laterally behind the front [55:72]." Interdiction can also directly support the air superiority mission, therefore interdiction during a theater campaign has high priority in many circumstances. The mission area is separated into the three categories distant, intermediate, and close. Distant entails "an attack against the source of men and materiel [55:80]," targeting resource sources, industry, ports, airfields, command and control networks, transportation networks, and enemy supplies such as ammunition, manufacturing, and oil refining. Intermediate attacks "somewhere between the source and the front [55:81]," such as enemy bivouacs, transportation nodes, depots, and theater level moving targets. Finally, close attacks are "in that area along the front where lateral movement takes place [55:80]" — moving targets near the battlefield.

The last mission area, close air support, is "any air operation that theoretically could and would be done by ground forces on their own, if sufficient troops or artillery were available [55:87]" and is directed toward ground combat at the battlefield, just in front of engaged friendly forces. This segment of an air campaign has lowest priority relative to air superiority and interdiction. Only when a critical ground battle defeat is

iminent or sufficient air resources are available — not effecting the air superiority and interdiction missions — are close air support missions usually enacted.

Considering target prioritization, air superiority is the primary objective for the theater commander, but may not be reachable initially. Defensive considerations may compel the commander to strike first at something other than the final objective, such as airfields and ground-based defenses. In theater conflict, the priority order of the air combat missions is 1) air superiority, 2) interdiction, and 3) close air support. There will be times when an interdiction and/or close air support mission will temporarily have higher priority. Concentration is the most important principle of air war; therefore, it is extremely dangerous to try other missions before air superiority is won. Clearly, air superiority must be the first *air* priority [55].

The combat model developed, the imagery tactical air combat simulation (TACSIM II), incorporated some of the ideas developed by Warden on air campaign planning [55] and Sovaiko's TACSIM model [51]. A detailed description of the simulation is contained in chapter 4.

2.3.4 Outcome Effectiveness Measures Selection. A theater air campaign is designed to kill targets. Table 2.1 and Warden's material discussed above point to number of targets killed as the best indication measuring operational effectiveness. Percent of fixed and mobile targets destroyed was chosen for measuring the choice between the integration center locations and the utility of imagery in theater conflict.

2.3.5 Imagery and Air Combat Model Assumptions.

1. 100 percent warning, surveillance, and weather satellite availability [36].
2. 100 percent communication satellite availability [36].
3. A target hit is a target kill [51].

2.4 Summary. This chapter establishes the need for an integrated imagery space support center based on experience in the Gulf War. Modeling the alternatives mentioned and determining what force qualities are important to theater air campaign planners is the meat of the following two chapters.

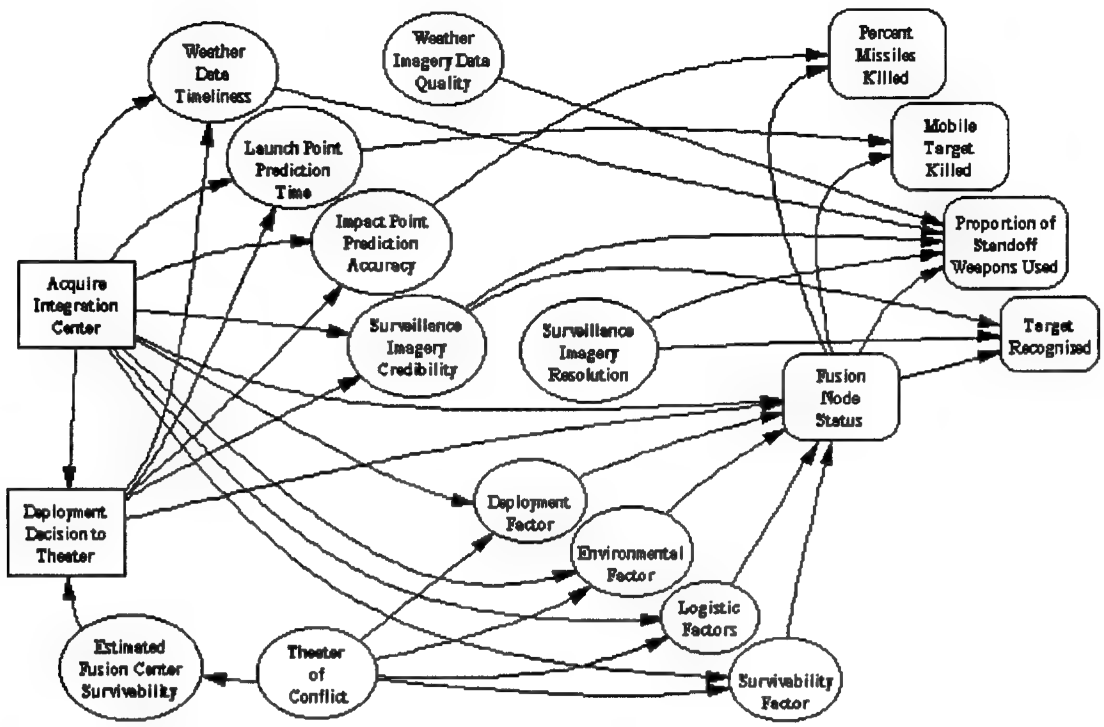


Figure 3.1: Influence Diagram for the DPL™ IMSIM model.

3.1 Decision to Acquire Space-based Imagery Integration Node. The DPL model examines the optimal decision on which fusion center type is best to acquire based on number of targets killed and cost. The fusion center alternatives used for the imagery analysis are Air Force Space Command's SHADOW Project (representing a version of a theater level center) and Talon Shield [operationally known now as ALERT (Attack Launch Early Reporting to Theater)] (an existing CONUS based fusion center). The decision alternatives in IMSIM for acquiring a fusion center are:

1. Fusion Node Based within Theater.
2. Fusion Node Based within CONUS.
3. Fusion Nodes Based within Theater *and* CONUS.

As a baseline for comparison, we evaluated the Desert Storm case. The IMSIM model focuses on the imagery air combat mission planners require to plan and conduct an

effective air campaign within a theater of operations. The three imagery based mission areas considered are warning, surveillance, and weather.

3.1.1 Estimated Fusion Center Survivability. Before deploying a transportable imagery fusion center, decision-makers must consider the expected survivability when placed in the particular theater environment. The discrete survivability probabilities used in the DPL IMSIM model are tabulated below.

		Fusion Center Estimated Survivability	
		Operational	Destroyed
Theater of Conflict	NE Asia	0.6	0.4
	SW Asia	0.8	0.2
	SE Europe	0.9	0.1
	Central America	0.98	0.02
	Caribbean	0.9998	0.0002

3.1.2 Theaters of Conflict. The following theaters were considered by IMSIM and TACSIM II.

1. Northeast Asia (Korean Peninsula)
2. Southwest Asia (Kuwaiti Theater)
3. Southeast Europe [European Slavic Region (Serbian Incursions)]
4. Central America (Invasion of Panama)
5. Caribbean Islands (police action in Haiti)

Deployment, logistical support, and environmental and combat survivability pertaining to these theater contingencies must be considered. Other threat environments or scenarios can be added at will since this model is easily modified. The probability of any given theater conflict occurring are assumed to be equal.

		Probability of occurring
Theater of Conflict	NE Asia	0.2
	SW Asia	0.2
	SE Europe	0.2
	Central America	0.2
	Caribbean	0.2

3.2 Decision to Deploy Fusion Node to Theater Conflict. The decision to deploy a theater imagery data fusion center to any theater in support of warfighters — either yes or no — is a function of the decision to acquire a theater node and the *estimated* node survivability, which in turn depends on the theater being considered. The DPL model will examine the optimal decision an whether to deploy or not based on value. Contingent on the decision whether to deploy a theater center or not, are many IMSIM uncertainty nodes and their probability distributions. These nodes are listed below.

Warning segment:

- Impact point prediction accuracy
- Launch point prediction time

Surveillance segment: Surveillance imagery credibility

Weather segment: Weather imagery data timeliness

3.3 Warning Segment. DSP infrared (IR) warning imagery is the source of data for this segment of the IMSIM model. DSP's mission is to detect the IR signatures of missile launches and aircraft afterburners to determine the launch, impact points, and trajectories of these targets. The focus will be on missile launch detection. Theater mission planners use the data generated from DSP IR detection to direct theater warfightering forces in attacks on the enemy mobile and fixed launch platforms and on intercepts of the enemy missiles and aircraft before they can reach their intended targets.

The raw IR imagery detected from DSP, assuming the satellite system is fully operational and available, can be downlinked directly to theater. The theater commander is not interested in false alarms at this level of command — which is not true at the strategic level, of course — since *any* detection is important. The unclassified false alarm rate for DSP is 1 per every 100 alerts [36]. Critical data includes missile launch plume and aircraft afterburner IR signatures. For any detections of this sort, the theater commander needs immediate warning so assets can be brought to bear to counter the enemy threat, i.e., Patriot ABM batteries to counter incoming, launched missiles; air-to-ground attack

aircraft to destroy previously undetected missile launch platforms and airfields; and air-to-air aircraft to counter and defend against enemy aircraft being deployed which were detected from their afterburners. Any detection can be expected to be supplied to the theater within 45 seconds to 120 seconds of occurrence from a CONUS based fusion center. The time line can be reduced to within 30 seconds to 90 seconds by a fusion center based directly within theater [21].

Viewing or aspect angle of an event is important to the warning mission. In warning, the angle at which DSP views an event has a lot to do with how quickly an accurate assessment can be determined. DSP is a geosynchronous satellite. As IR events occur higher in latitude, i.e., toward the earth's poles, the maximum amount of time required to get processed data to theater increases from 120 seconds to 210 seconds. Events seen at large aspect angles take more time to detect and evaluate.

Weather conditions, in particular cloud cover, are of paramount concern to the warning mission area. IR warning can not penetrate cloud cover, although radar multispectral surveillance is unrestrained by weather. If a target is obscured, warning IR is extremely limited in its ability to detect anything.

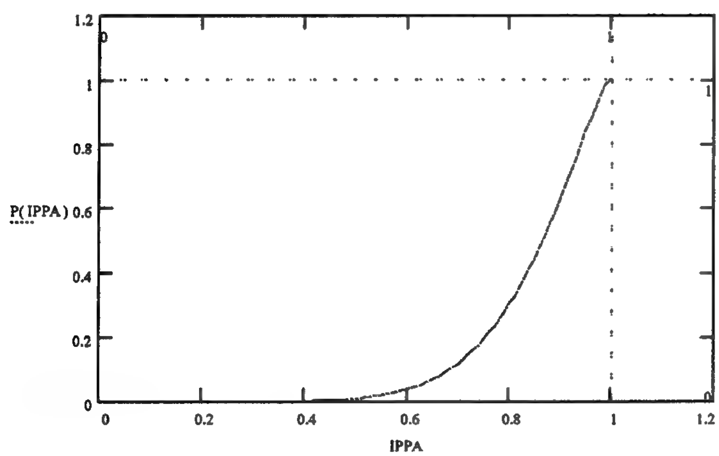
> The timeliness of DSP launch detection data was key in Desert Storm. Iraqi Scud teams could launch a missile and drive away and hide under cover in less than five minutes. Raw launch data from DSP was downlinked to ground processing centers and routed to the central DDC at Buckley before being sent to Central Command's headquarters in Saudi Arabia, costing precious time. 'Scud CAP' aircraft usually did not get launch point data in time to knock out Scud launchers, but Patriot batteries did get the data in time to defend against the Scuds themselves. The two key problems here were launch data timeliness and distribution of this data to the warfighter [17:183].

3.3.1 Impact Point Prediction Accuracy (IPPA). The impact point prediction accuracy is a function of fusion center processing capability determining the vicinity where a particular missile is expected to strike. IPPA also accounts for the number of confirmed and false alarms reported. Further, the processing capability is a function of node location, presuming the capabilities of a mobile theater node are slightly less than a fixed CONUS node. Theater warning alerts are assumed to be less accurate since theater

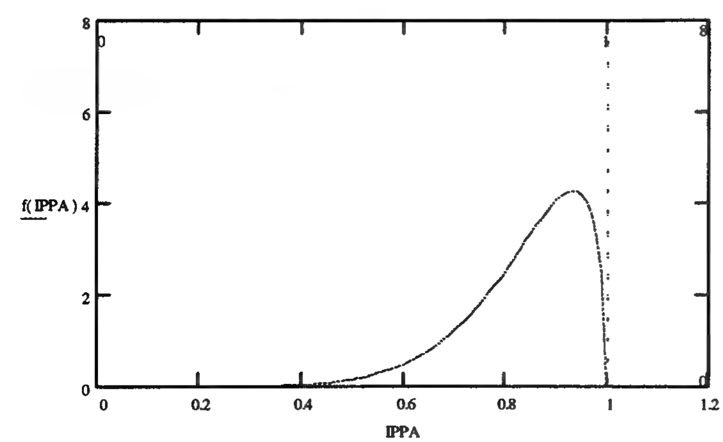
planners desire all data and are not concerned about whether a signal is false or not. Greater care is taken — or more time is wasted depending on perspective — in a CONUS fusion center to reduce the number of false alarms relayed to the theater. This increases the accuracy of the impact point reports processed within CONUS before release to the theater. The warning time necessary for defensive measures is assumed to be adequate from either a theater or CONUS center in this model. The IPPA uncertainty node essentially considers where missiles should impact, depending upon their detected trajectories, so appropriate defensive batteries can be alerted. The impact point prediction accuracy uncertainty node is modeled as continuous beta probability distributions.

THEATER:	$\alpha = 8.0$	mean = 0.84211
	$\beta = 1.5$	variance = 0.012663

Cumulative Distribution Function:

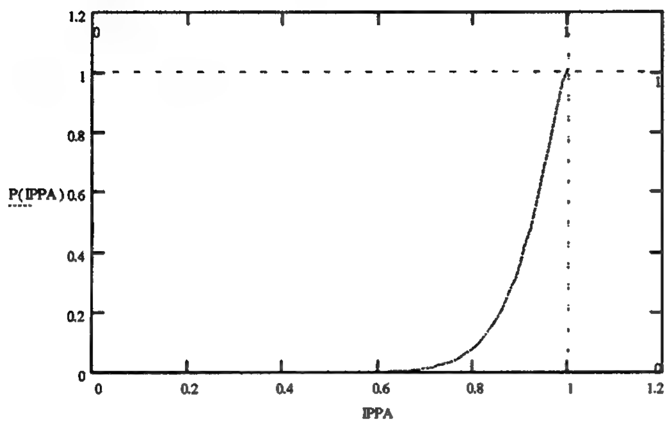


Probability Density Function:

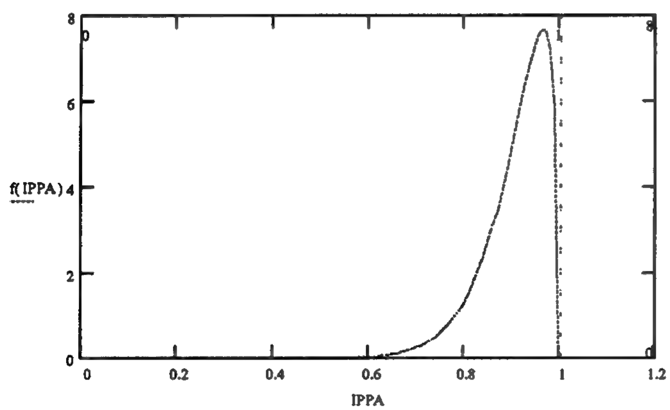


CONUS and BOTH: $\alpha = 15.00$ mean = 0.9091
$\beta = 1.50$ variance = 0.0047226

Cumulative Distribution Function:



Probability Density Function:



3.3.2 Launch Point Prediction Time (LPPT). The launch point prediction time is a function of fusion node location and accounts for timely detection of mobile and fixed missile launch locations. Launch point prediction time is the speed launch points can be determined and disseminated after launch detection. Rapid prediction time is critical so theater air forces can attack mobile launch platforms before these platforms pack up and relocate. This worst case time line must be less than 3 to 5 minutes (180 to 300 seconds). A theater integration node with direct satellite downlink reception and raw data processing capabilities reduces the overall warning data dissemination delay to users. A CONUS node involves many unnecessary transmit and receive delays in providing processed

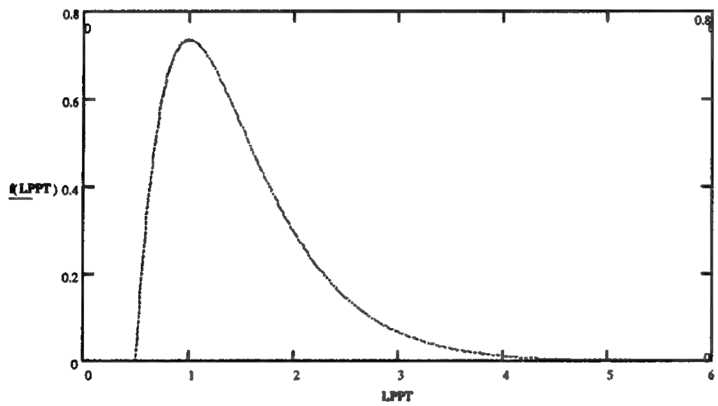
warning data. Launch point determination times for theater and CONUS fusion centers are modeled as gamma distributions.

THEATER and BOTH: Gamma(2.0, 0.5) in minutes

$\alpha = 2.0$ mean = 1.0 minute

$\beta = 0.5$ variance = 0.5

The variable *LPPT* in the graph below represents the launch point prediction time.

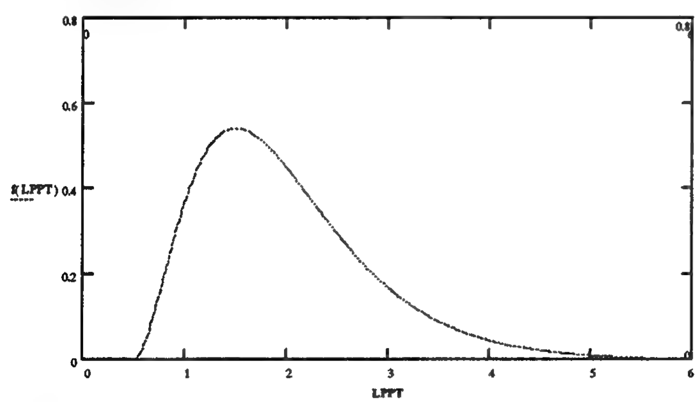


CONUS: Gamma(3.0, 0.5) in minutes

$\alpha = 3.0$ mean = 1.5 minutes

$\beta = 0.5$ variance = 0.75

The variable *LPPT* in the graph below represents the launch point prediction time.



3.4 Surveillance Segment. Landsat and SPOT remote sensing imagery are the sources of data for this segment of the IMSIM model. Spatial resolution of imagery is important in surveillance for target identification and recognition. *Resolution* is defined as "the

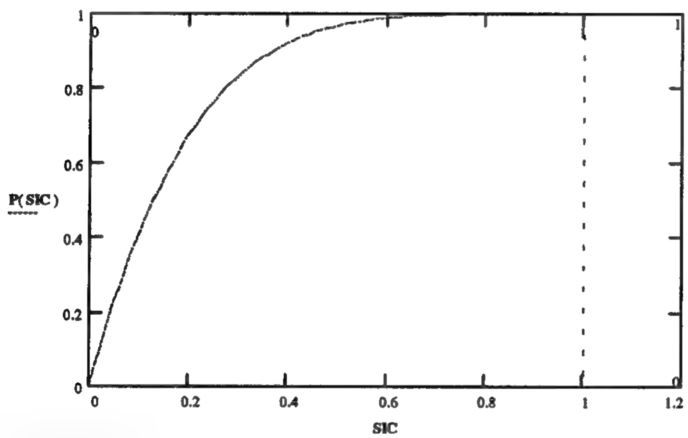
ability of a remote earth sensing system to distinguish an extended object from a point [46:80]." Second, and related to spatial resolution, is aspect angle resolution. The viewing angle of an event is important to surveillance. Aspect angle resolution with respect to surveillance decreases as the angle increases. The two surveillance platforms, Landsat and SPOT, are in circular, polar orbits. Their best resolution are 30m and 10m, respectively. As the platform's viewing angle increases, the best resolution achieved decreases. Finally, weather conditions, in particular cloud cover, is of paramount concern to the surveillance mission area. If a target is obscured, surveillance photo platforms are extremely limited in their abilities to detect anything.

3.4.1 Surveillance Imagery Credibility (SIC). The credibility of surveillance imagery is a function of the age and, subsequently, the relevance of the data obtained. Surveillance imagery is useful for combat mission planning, execution, and battle damage assessment (BDA). Imagery is used in mission planning and execution for target identification, route selection, weapons selection and targeting. New and recently archived data is of greatest value for the planning and execution phase of combat operations while old data has little benefit. Imagery used for BDA is essential in determining mission outcome and damage estimation on enemy targets. During the Gulf War, "BDA was critical because from it, planners would determine if a target had been destroyed or if additional strikes were required [56:75]." Combat resources are expensive and limited, therefore mission planners want to devote the least amount of combat sorties against any single target. *Only* new imagery obtained from the satellite platforms and disseminated to the theater mission planners within the twelve hour ATO cycle, beginning at the time of the original air strike, is of value in determining whether a second sortie is required. Any archived data will generally not be applicable for BDA. Of course, if a second strike was not projected during the follow-on ATO cycle, the timeline for BDA imagery can be extended. For this thesis, BDA imagery is assumed to be needed for every twelve hour ATO since the decision to send another sortie is directly dependent on the outcome of the original strike. A CONUS fusion node requiring overseas data

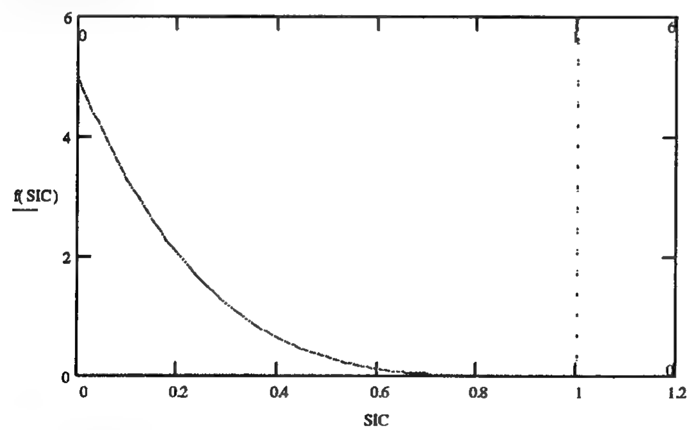
transmission relays would delay the dissemination of new and archived data slightly more than a theater node. In addition, a theater node with raw data downlink and processing capability will increase the timely dissemination of imagery to the theater planners. The timeliness of *archived* imagery data is not a function of node center location. The credibility of surveillance imagery collected by a CONUS fusion node can be modeled as a beta distribution with the following parameters:

$\alpha = 1.0$ mean = 0.16667
$\beta = 5.0$ variance = 0.019841

Cumulative Distribution Function:



Probability Density Function:

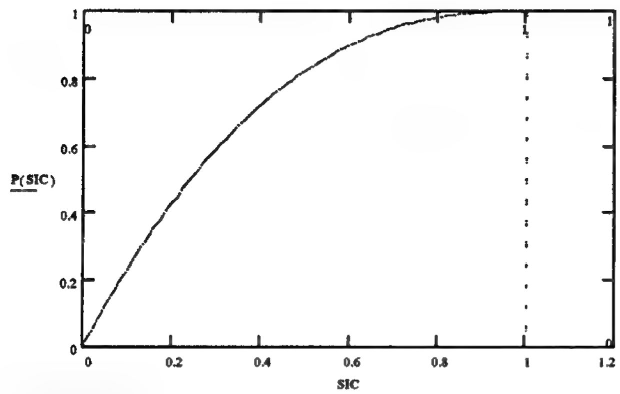


The credibility of surveillance imagery collected by a theater fusion node and both a CONUS and theater center can be modeled as a beta distribution with the following parameters:

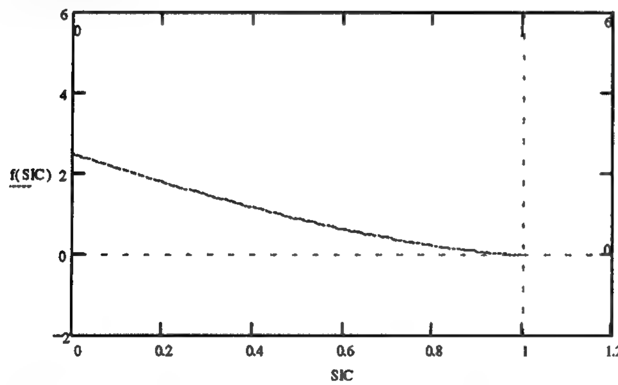
$\alpha = 1.0$ mean = 0.28571

$\beta = 2.5$ variance = 0.045351

Cumulative Distribution Function:



Probability Density Function:

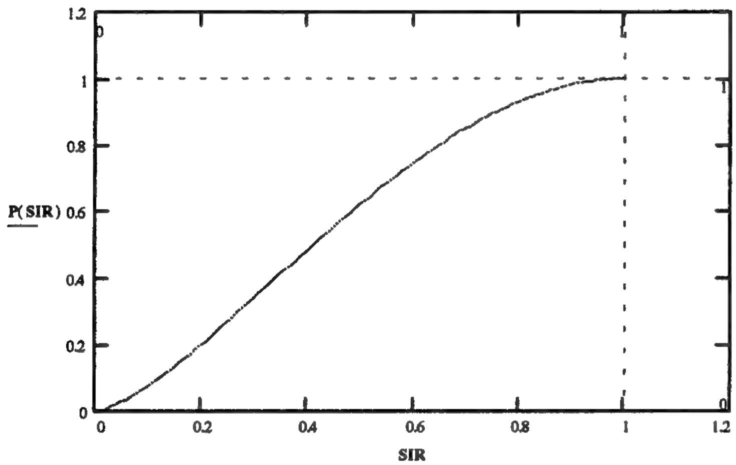


3.4.2 Surveillance Imagery Resolution (SIR). The quality of surveillance imagery is essentially determined by the satellite's field of view and aspect angle viewing a target, the resolution capability of the system, and terrestrial weather conditions [46; 34]. Poor resolution and environmentally obscured imagery are ineffective for supporting combat mission planning and battle damage assessment (BDA). Satellite revisit time and weather conditions over targets can cause delays in obtaining appropriate imagery in support of theater requirements. The impact imagery resolution will have on combat is essentially relative to weapons choice during mission planning and target recognition by pilots during mission execution. The probability theater planners will get effective imagery within the twelve hour ATO cycle is modeled as a beta probability distribution. The

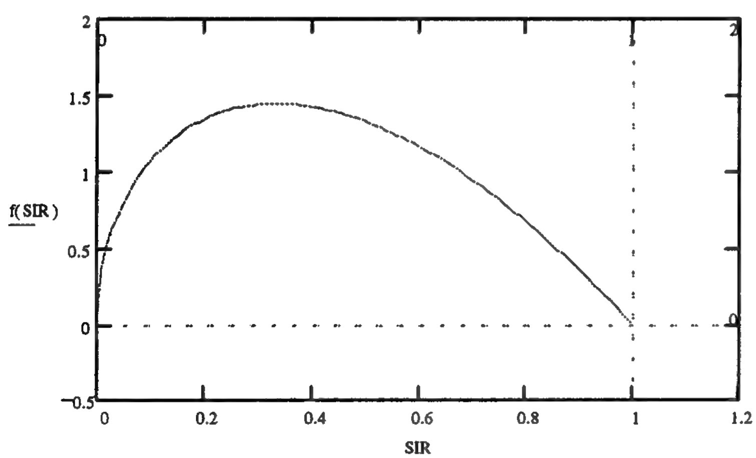
resolution of surveillance imagery collected by a theater, CONUS, and both a theater and CONUS fusion node is modeled as a beta distribution with the following parameters:

$$\alpha = 1.5 \qquad \text{mean} = 0.42857$$
$$\beta = 2.0 \qquad \text{variance} = 0.054422$$

Cumulative Distribution Function:



Probability Density Function:



3.5 Weather Segment. DMSP, NOAA, and GOES imagery are the sources for weather data for this segment of the IMSIM model. The meteorological imagery is essential to the air combat planner in identifying weather conditions over appropriate targets — fixed and mobile enemy land, sea, and air military, and industrial targets — and optimum route selection to the targets. Weather conditions over a target dictate 1) when

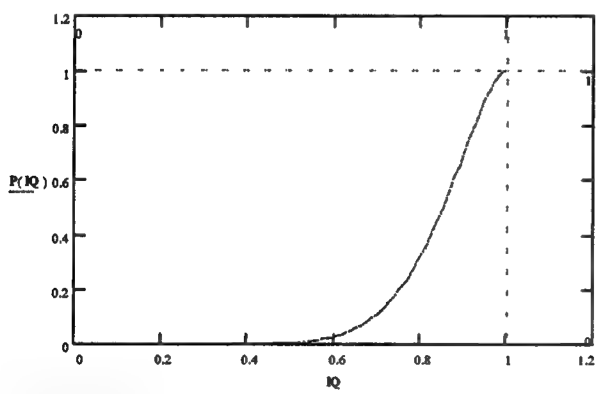
to attack a target (bad weather may delay the attack), 2) what weapons package and platform to use against the target (determined by type of weather over the target), and 3) atmospheric conditions over the target. Two forms of data are used by the warfighter: picture imagery and prep file data [36].

3.5.1 Weather Imagery Data Quality (WIDQ). The quality of weather imagery is determined by the satellite's field of view and resolution capability. Resolution is dependent on the equipment onboard the satellite while field of view is dependent on the satellite's orbit. Weather imagery is not functionally affected by weather conditions or the fusion center's location. Good quality weather imagery will improve mission planners' abilities to select the most effective weapons and routes against enemy targets, increasing the probability of success on individual sorties. The quality of weather imagery can be modeled as a beta distribution with the following parameters:

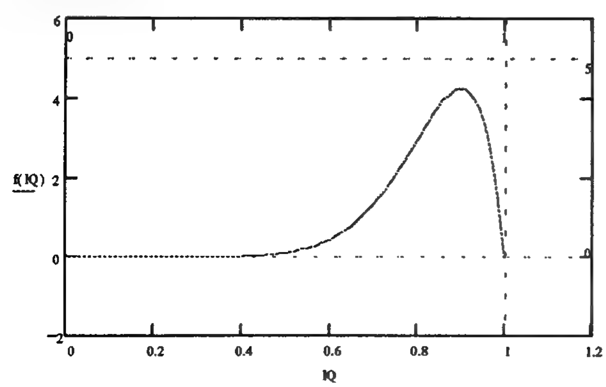
$\alpha = 10.0$ mean = 0.833333

$\beta = 2.0$ variance = 0.01068376

Cumulative Distribution Function:



Probability Density Function:



3.5.2 Weather Imagery Data Timeliness (WDT). Timeliness is the time margin from when data arrives until it is needed [32:61]. Imagery either arrives within or outside the time margin. Weather imagery timeliness is a function of the fusion center's location. A theater center with raw data downlink and processing capability will reduce one to two hours off current data dissemination time [36]. The probability of obtaining data within the warfighter's required time margin is important in determining the fusion center's location. Weather imagery must arrive in theater under 8 hours (480 minutes or 2880 seconds) to support the 12 hour Air Tasking Order (ATO) developed by planners.

THEATER and BOTH:	Uniform(0.0333, 6) mean = 3.01665 hours; variance = 2.9668
CONUS:	Uniform(0.3667, 9) in hours mean = 4.68335 hours; variance = 6.2112

3.6 Integration Center Segment. The issues pertaining to deployment of an integration center to a theater conflict are taken into account within the fusion center segment of the DPL model. The fusion center is assumed to be deployed to any one of the five theaters as listed earlier.

3.6.1 Deployment Factor (DF). The deployment factors uncertainty node in DPL is a composite of the most significant deployment problems anticipated for the five locations for theater level conflicts listed earlier. This uncertainty node considers the probability of attaining a fully effective and operational integration center. The factors are: 1) the probability of any hardware damage to the fusion center upon deployment, 2) the probability of fusion node deployment delays, 3) the probability of a critical, non-repairable failure of the fusion center upon deployment. This node is modeled as a uniform continuous distribution. The deployment factor will range between 0 and 1. The larger the number of days to deploy, the smaller the value given to the variable. Any deployment delay will reduce the fusion center's deployment factor directly proportional to the length of any delay.

		Deployment Factor
Theater of Conflict	NE Asia	Uniform(0.7,1)
	SW Asia	Uniform(0.7,1)
	SE Europe	Uniform(0.8,1)
	Central America	Uniform(0.995,1)
	Caribbean	Uniform(0.995,1)

3.6.2 Logistic Factors (LF). The logistic factors uncertainty node anticipated fusion center logistics requirements, corresponding to either a transportable node in theater, a fixed node in CONUS, or one of each at both locations. These logistics factors include: fuel for power generation; maintenance supplies or spare parts and a corresponding shelter — all dependent on how much maintenance will be required for the node; and personnel factors such as food, clothing, shelter, and any morale, welfare, and recreational needs deemed necessary for the deployed personnel. This factor will range between 0 and 1, identifying the fusion node's operability due to logistic factors [31:11-13]. This node is modeled as a uniform continuous distribution depicting how the space fusion center gets fuel, spare parts, personnel needs, and maintenance as required for effective combat operation.

		Logistic Factors
Theater of Conflict	NE Asia	Uniform(0.8,1)
	SW Asia	Uniform(0.8,1)
	SE Europe	Uniform(0.95,1)
	Central America	Uniform(0.995,1)
	Caribbean	Uniform(0.9995,1)

3.6.2 Survivability Factor (SF). This uncertainty node is concerned with the survivability of the imagery fusion center throughout a theater level conflict as a function of it's deployed location. The fusion center deployed to an overseas theater of operations is assumed to be collocated with the theater CINC and air component commander's headquarters. The node's probability of survival, therefore, should be the same as for the theater headquarters. A fixed node within CONUS will have a very high probability of survival, assuming the enemy within a theater conflict has no long range attack capability.

For this thesis, the probability of survival for the fixed, CONUS center is to be 1.0 for the worst case theater scenario — conflict on the Korean Peninsula. Node survivability is modeled as a continuous uniform distribution representing the fusion center's survivability in a combat environment.

		Survivability Factor
Theater of Conflict	NE Asia	Uniform(0.8,1)
	SW Asia	Uniform(0.8,1)
	SE Europe	Uniform(0.9,1)
	Central America	Uniform(0.96,1)
	Caribbean	Uniform(0.9996,1)

3.6.4 Environmental Effects Factor on Fusion Node (EF). The environmental effects on the fusion center are directly dependent on the theater in which the fusion center is operating. Each theater has any number of distinct environmental factors to contend with. For instance — within the Persian Gulf — heat, sand, and open terrain are instrumental factors the node must be able to withstand. In the Korean Peninsula, all forms of weather and terrain are important to consider — torrential rains 3-4 days running, rock slides, rice paddies everywhere, mountains, mud, boggy roads, very hot and cold temperatures, winters at night being -20°to -30°F and in daytime 0°F, howling blizzards, and overcast skies [33 and 54]. The worst case scenario for the fusion node, the theater of operations where the most intense environmental factors will be endured, is the Korean Peninsula. Therefore, if the fusion node is designed to withstand the environmental effects in Korea, the node should handle any other theater of operations fairly well. This uncertainty node models the fusion node's environmental survivability as a uniform continuous probability distribution

		Environmental Factor
Theater of Conflict	NE Asia	Uniform(0.8,1)
	SW Asia	Uniform(0.95,1)
	SE Europe	Uniform(0.8,1)
	Central America	Uniform(0.95,1)
	Caribbean	Uniform(0.9,1)

3.6.5 Node Status (NS). This value node accumulates the values determined by the four previous uncertainty nodes, providing a single factor to measure the space fusion center's impact on mission outcome. This node is a product of the previous four uncertainty node factors, which were node survivability, deployment, logistic, and environmental effects. The outcome value from this node will range between 0 to 1.

$$\boxed{NS = DF \cdot LF \cdot SF \cdot EF}$$

3.7 Summary. This chapter summarizes the key force qualities involved in space-based imagery and the factors relative to an integrated space support center deployed to secific theaters of conflict. These qualities and their quantities form the basis for the Imagery Simulation (IMSIM) model. Transferring these force qualities into the realm of air combat is the subject of the next chapter. In chapter 4, the discussion show how the imagery and node status force qualities interact on air combat through a second model called the Tactical Air Combat Simulation II (TACSIM II).

4.1 Air Combat Segment. TACSIM II, Figure 4.1, simulates 1 wing of 72 aircraft, each carrying 2 weapons per sortie and capable of 2 sorties per day, depending upon aircraft mission capable rates. There is an unlimited target set available to the model. The simulation will be conducted for a 30 day campaign time period [51:20-33].

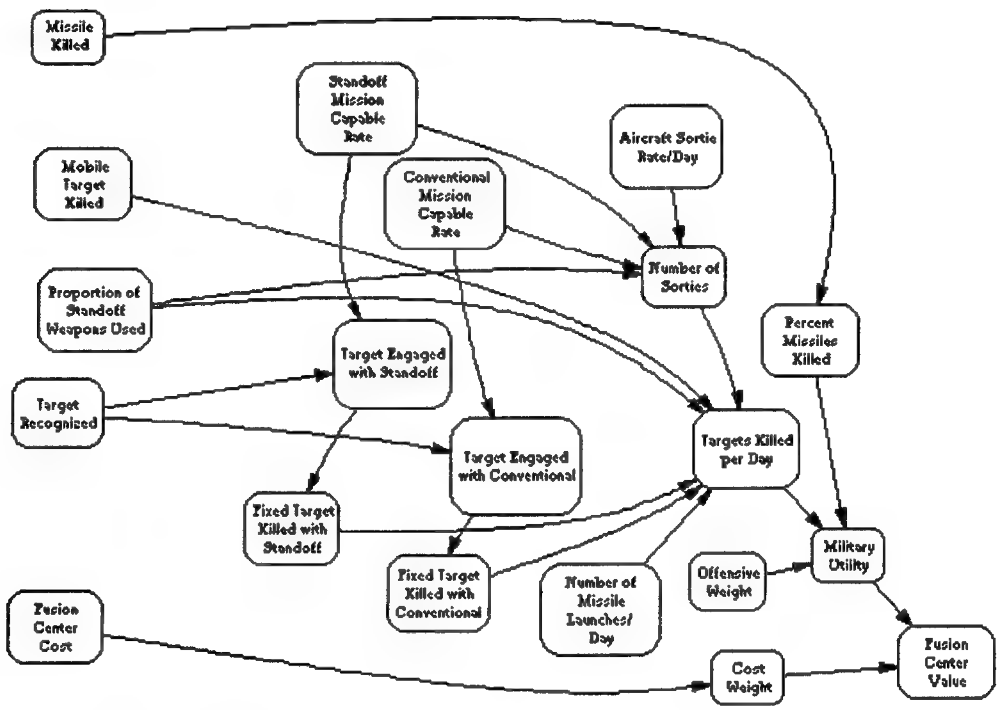


Figure 4.1: Influence diagram for the DPL TACSIM II model.

4.1.1 Target Recognized (TR). This deterministic event node assesses the probability a single sortie locates and identifies an enemy target having the benefit of target imagery support. Imagery is used during mission planning and in combat mission target folders carried by aircrews during execution of their mission. Target recognition by combat pilots and weapons officers during mission execution is evaluated as a function of surveillance imagery credibility (SIC) and resolution (SIR) as well as status of the fusion center; whether it's in theater, CONUS, or both the theater and CONUS. During the Gulf War, 80 percent of all strike aircraft reached their targets, delivered their ordinance, and

returned. The 20 percent not completing their mission was predominately due to problems in target recognition [56:65]. Visual identification of targets was a rule of engagement during the Gulf War [17:177]. Assuming a linear increase ranging from 80 to 100 percent in target recognition with the addition of imagery data support, the equation in the DPL TACSIM II simulation for target recognition is:

$$\boxed{\text{Probability Target Recognized } [P(TR)] = 0.8 + 0.2 \cdot NS \cdot (SIC \cdot SIR)}$$

4.1.2 Missile Engagement (ME). A Scud missile engagement occurs between ground anti-tactical ballistic missile defenses against incoming enemy missiles and is represented by a deterministic node within the TACSIM II DPL model. The probability of engaging the missile, or P(ME), is equal to 0.96 [17:185]. Therefore, the probability of not engaging the missile is one minus P(ME), or 0.04.

4.1.3 Target Engagement (TE). Target engagement is the likelihood of the weapon delivery platform — an aircraft in this simulation — actually engaging a target and is a function of aircraft missio capable rate (MCR) and target recognition. This likelihood grows when accurate, credible, and high resolution imagery is available supporting precision delivery and standoff capability by increasing the target recognition variable defined earlier. The equations for target engagement below reflect the difficulty in engaging targets as imagery degrades.

	Target Engaged [P(TE)]
Conventional	(Conventional MCR)·TR
Standoff	(Standoff MCR)·TR

4.1.4 Mobile Target Killed (MTK). This value node calculates the probability mobile targets, or transportable missile launch platforms, are killed given 1) a probability a weapon will hit its intended target and 2) the amount of time involved in predicting the missile's launch point from launch detection by DSP through processing to determine the launch point accurately to receipt by combat planners in the theater of operations. The operational status of a theater fusion center, if any, is also factored into this value.

Aircraft poised to attack mobile targets — assumed to be mobile launch platforms in relatively remote areas without antiaircraft support — are in orbiting combat air patrols, therefore a decision to use standoff PGMs or conventional iron bombs is made before the mission begins. The relatively low threat posed by assuming little to no enemy antiaircraft support alleviates many of the reasons for using standoff weaponry. The weaponry used for each attack on detected mobile targets are two conventional iron bombs for each aircraft sortie.

$$\boxed{\text{Mobile Target Killed Probability [P(MTK)]} = \text{NS}\cdot\{\max[(4.5\text{-LPPT})/4.5,0]\}}$$

No useful launch detection data will arrive in theater under 30 seconds (0.5 minutes). The launch point must arrive in theater in less than five minutes to be of value to the theater warfighter. The operational effectiveness utility of the launch point prediction time is determined by setting the best time (realworld LPPT = 0 minutes) at 1 and the worst (LPPT = 5 minutes) at 0 and drawing a linear relationship between the two for LPPT values falling between 0 and 5 minutes.

4.1.5 Percent of Missiles Killed (%MK). The killing of an incoming enemy Scud missile is a function of DSP's IR warning imagery impact point prediction accuracy (IPPA), the probability of engaging the missile, and the operational status of the imagery fusion center. Missile kill is represented in the following equation.

$$\boxed{\text{Missiles Killed Percentage [\%MK]} = \text{P(ME)}+0.04\cdot\text{IPPA}\cdot\text{NS} = 0.96+0.04\cdot\text{IPPA}\cdot\text{NS}}$$

4.1.6 Fixed Target Kill (FTK). This value node represents whether a weapon released from an aircraft during a sortie will actually hit its intended target. All targets are assumed equal in air-defense protection, hardness, and target value for this analysis. A target hit is assumed to mean a target kill [51:30-31]. The following table provide the kill probabilities assumed for this analysis. An important statistic from the Gulf War is the fact 79% of all bombs dropped hit within 10 feet of their target and the hit percentage for

PGMs was 96% [17:177]. The discrete fixed target kill probabilities used in this node are those extracted from the Gulf War.

Bomb Type	*Fixed Target Kill Probability* [17:177]
Conventional Iron bombs:	0.79
PGMs:	0.96

The target kill probabilities are each assumed to increase to one as imagery support to air combat planning is increased.

	Fixed Target Killed Probability [P(FTK)]
Conventional	$0.8 + 0.2 \cdot TE$
Standoff	$0.96 + 0.04 \cdot TE$

4.1.7 Number of Missile Launches (#ML). The rate set in the DPL TACSIM II model is 2.2 enemy missile launches per day since there were 93 Iraqi Scud missiles fired during the 43 day Gulf War [17: 185]. Each missile launch is assumed to originate from a transportable launch platform.

4.1.8 Proportional Use of Standoff and Conventional Weapons [(∝ Stoff) or (∝ Conv)]. The definition of a standoff sortie is one engaging a target from a distance using precision guided munitions (PGM) [51:29]. Any sorties not using PGM weapons are assumed to deliver conventional bombs. The proportion of sorties using standoff weapons and tactics is a deterministic event node as a function of the fusion node status, weather imagery data quality and timeliness, and surveillance imagery credibility and resolution. Without any sort of imagery fusion node, the fraction of Desert Storm PGM bomb tonnage dropped by the coalition air forces was 0.09 [8:116; 17:188]. Assuming an increase ranging between 9 to 25% in the use of standoff weaponry because of increased PGM availability and imagery support, the following table identifies the proportion of sorties using standoff weapons and tactics incorporated into the DPL TACSIM II model.

	Proportion (∝) of total sorties using standoff and conventional weapons and tactics
Standoff	$0.09 + 0.16 \cdot NS \cdot \{0.06 \cdot WDIQ + 0.24 \cdot [\max((8-WDT)/8,0)] + 0.7 \cdot (SIC \cdot SIR)\}$
Conventional	1 - Standoff

The weights arbitrarily assigned to the imagery data variables — WDIQ, WDT, SIC, and SIR in the above equation — represent the significance of each variable to the theater air campaign planners and can be adjusted as required.

Imagery Variable	*Weight Value*
WDIQ	0.06
WDT	0.24
SIC·SIR	0.70

4.1.9 Mission Capable Rate (MCR). The aircraft mission capable rate is a function of the aircraft maintenance capability. "Due to [BG Motti] Hod's relentless pursuit of excellence beyond the cockpit, Israeli ground crews could rearm and refuel a jet fighter-bomber in literally minutes [witnessed during the 1967 Isreali-Arab War], as against a world-wide standard of as long as several hours [18:130-131]." Pre-war estimates of Gulf War MCRs ranged from 0.8 to 0.95 for air-to-air and air-to-ground combat aircraft [8:128; 17:155-156]. The MCR probability assessments are listed below.

	Mission Capable Rate
Conventional	0.85
Standoff	0.92

4.1.10 Aircraft Sortie Rate/Day. The deterministic sortie rate for this simulation is two sorties per day per available aircraft [51:32]. Results from the Gulf War suggests this rate went as high as seven per day [17:188].

4.1.11 Number of Sorties (#S) on Fixed Targets. The number of sorties flown each day during a 30-day campaign is limited by the number of aircraft surviving each day and the sortie rate constraint. For each campaign day, the 72 aircraft attempt to fly two sorties each, but, as time goes by, some are lost to combat attrition and maintenance problems [50:32]. The number of sorties flown per day is given by this equation, assuming no attrition.

$$\boxed{\#S = (72\ \text{aircraft})\cdot(2\ \text{sorties/day})\cdot[(\propto \text{Conv}) + (\propto \text{Stoff})]}$$

4.1.12 Missile Battery Action Rate/Day. There are assumed to be 30 missile batteries within any given theater of operations, each capable of firing 4 Patriot antitactical ballistic missiles at each incoming enemy missile. The rate these batteries are required to strike down an enemy missile is set at 1.1 per day (there were 47 threatening missile attacks during the 43 day Gulf War) [8:56; 17:185; 56:225].

4.1.13 Number of Missile Attacks per Day (#MA/D). The number of times missile batteries within any given theater defend against missile attacks during the simulated 30-day capaign is limited by the Patriot battery action rates per day.

$$\boxed{\text{Number of Missile Attacks/Day} = (1.1 \text{ missile batteries/day})}$$

4.1.14 Number of Weapons/Aircraft Sortie (#W/S). The number of weapons carried per sortie is held at two for the simulation. The predominate PGMs used by the Air Force during the Gulf War were the Paveway and the Maverick missiles [8:116; 17:203].

4.1.15 Number of Weapons/Missile Attack (#W/MA). For this simulation, each Patriot missile battery employed will be limited to attacking any incoming enemy missile with 3.36 Patriot antitactical ballistic missile missiles — the average number used during Desert Storm for each Scud attack [17:185].

4.1.16 Percent of Targets Killed (%TK). The number of targets killed per day measures the combat effectiveness of imagery. This quantity is the sum of two products (ground targets and Scud launches) and normalized by dividing with the maximum number of sorties possible. The first is the number of Scud missile launches times the probability of killing the mobile launch platforms. The second is the product of the number of sorties flown per day, the number of weapons per aircraft, and the probability of kill for any given weapon.

$$\boxed{\%TK = \frac{(\#ML)[P(MTK)] + (2)(\#S)\{(\propto \text{Conv})[\text{Conv } P(FTK)] + (\propto \text{Stoff})[\text{Stoff } P(FTK)]\}}{\#ML + 2(\#S)}}$$

4.1.17 Military Utility (MU). Military utility is the combat measure of incorporating imagery data into theater air campaign planning and execution. Here, military utility accounts for offensive (the number of fixed and mobile targets killed) and defensive (the number of enemy tactical ballistic missiles killed) affects as evaluated by the IMSIM and TACSIM II models. Included in this evaluation is a variable emphasizing offensive — mobile and fixed target kills — versus defensive — tactical ballistic missile kills — measures of effectiveness relative to the value of the theater or CONUS fusion centers to theater planners. The factor illustrating the theater planner's weight pertaining to offensive and defensive aspects of the air campaign is termed "offensive weight" (OW) — set at 0.9 for this thesis. The equation for military utility is a function of percent of fixed and mobile targets killed and percent of incoming missiles killed.

$$\boxed{MU = OW\cdot(\%TK) + (1\text{-}OW)\cdot(\%MK)}$$

4.2 Cost Segment. The last segment of the IMSIM and TACSIM II DPL model considers the acquisition, logistic, and deployment costs of each of the imagery fusion centers. The beneficial value of each of the nodes in number of targets killed/day is also contained in this segment, although at a very simplistic level.

4.2.1 Fusion Center Cost (FCC). The estimated development, procurement, and operating costs for each of the three fusion centers are tabulated below by dollar amount per day. To convert to utilities, these dollar figures need to be normalized to between 0 and 1. The least expensive option, in this case the theater, transportable fusion center, is assumed to have the greatest utility, therefore the alternative is assigned a utility of 1. The most expensive choice — both a theater and CONUS fusion center — is assigned the lowest utility of 0. Assuming a linear relationship between the utilities assigned to the theater and both choices, the normalized CONUS utility value can be calculated from the equation below.

U(CONUS) = [(CONUS Cost) – (Theater Cost)]/[(Cost of both) – (CONUS Cost)]

Fusion Center Type	Estimated Fusion Center Cost ($K/day)	Cost Normalized for DPL Model
Theater	21.918 [21]	1
CONUS	36.986 [35:69]	0.407
Both	58.904	0

4.2.2 Fusion Center Value (FCV). The final measure of fusion center air combat value folds the cost of the center in with the military utility as calculated earlier with the DPL simulation. A "cost weight" variable has been included to evaluate the balance between cost and military utility of the fusion center. This measure can determine whether cost is prohibitive in acquiring a center.

$$\boxed{FCV = CW \cdot FCC + (1\text{-}CW) \cdot MU}$$

4.3 Summary. This chapter and it's predecessor described the force qualities pertaining to space-based imagery within an imagery integration center supporting a theater conflict, and their interaction with air combat planning and execution. The final step in this analysis is to run the IMSIM and TACSIM models to ascertain any significant effects on the military's warmaking capabilities compared to Desert Storm standards.

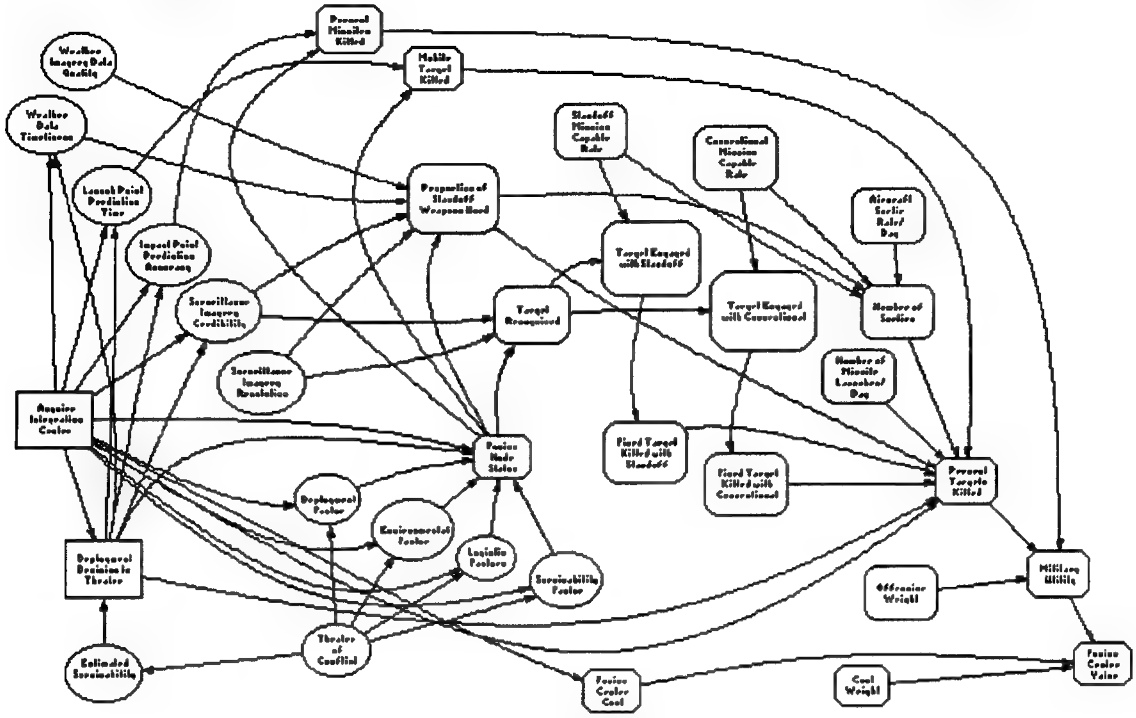


Figure 5.1: Influence Diagram of the combined DPL™ IMSIM and TACSIM II models.

5.1 Model Validation.

5.1.1 Desert Storm Comparison. The first step in validating the IMSIM and TACSIM II model was to determine Gulf War results with space-based imagery support. The space, cost, and node status segments of the combined model, Figure 5.1, were set at their worse case — zero for each. The values used within the TACSIM II model became the following [see chapter 4 for literature references]:

Percent Missiles Killed = 0.96.

Mobil Target Killed = 0.0. Throughout the Gulf War, no mobile launch platforms were destroyed as a result of DSP warning [43].

Proportion of Standoff Weapons Used = 0.09.

Target Recognized = 0.8. There was no up-to-date imagery of the Persian Gulf at the start of hostilities. Any new imagery of the region from Landsat and SPOT was brought in by courier or via facsimile no earlier than two to three days [17]. The IMSIM model requires imagery to be received by theater planners within 12 hours, not 48 to 72

hours. Imagery data from EOSAT, for instance, was usually sent to CENTCOM planners in Saudi Arabia via the Tactical Digital Facsimile (TDF). Transmission of imagery over this facsimile reduced the image's resolution [17].

Fixed Target Killed with Standoff/Conventional = 0.96/0.80.

Two simulation runs were conducted on this basic, Desert Storm level. For case A, offensive weight was set at 0.9 and for the second, B, the weight was reduced to 0.5. The table below summarizes the expected value of military utility based on the emphasis given to offense.

Case	*Offensive Weight*	*Expected Value (EV)*
A	0.9	0.823
B	0.5	0.884

Case A versus Case B: The results indicate by deemphasizing offensive capabilities, the military utility measure of effectiveness improves. This correlates with one of the main offensive factors from the Gulf War — killing mobile Scud launchers. None were killed as a direct result of space based warning imagery, therefore reducing the importance of this capability improves overall value. The TACSIM II model effectively captures this balance between offensive and defensive measures. During the rest of the IMSIM and TACSIM II analysis, the offensive weight will be kept at 0.9, reflecting the warfighter's offensive emphasis over defense.

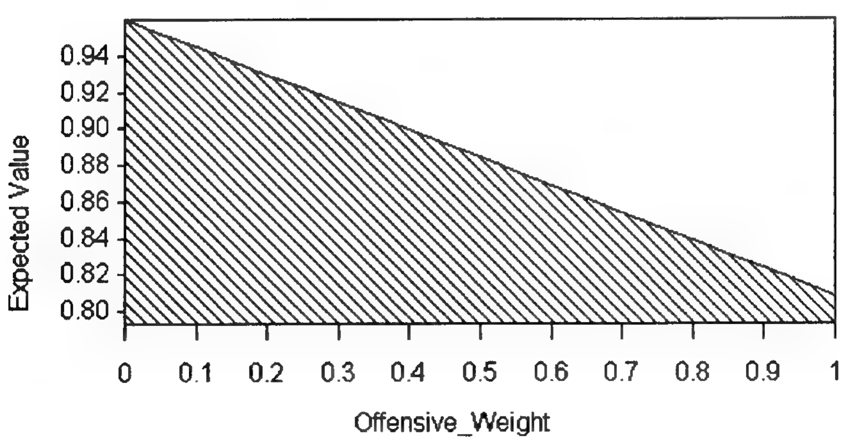


Figure 5.2: Rainbow diagram illustrating effects of offensive weight on Gulf War operations.

5.1.2 Model Segment Analysis. In this portion of the IMSIM and TACSIM II validation, each of the three segments of the model — space, node, and cost — were individually examined to evaluate their impact and how the model captures their nature. Four simulations were run with offensive weight assumed to be a constant 0.9. The table below summarizes the differences between each of the cases examined.

CASE	*SPACE*		*NODE STATUS*		*COST*	
	Probabilistic	*Perfect*	*Probabilistic*	*Perfect*	*Yes (0.4)*	*No (0.0)*
1		X		X		X
2	X			X		X
3	X		X			X
4	X		X		X	

Case 1: This is a perfect world representation of the IMSIM and TACSIM II models — the space, node status, and cost segments are 1, 1, and 0, respectively. As expected, the DPL simulation run evaluates all three integration center acquisition choices as equivalent. A comparison between the military utility expected value for acquiring an integration node relative to Gulf War experience is shown below.

Comparisons	*Expected Values*
Integration Center Available	0.979
Desert Storm	0.823

The table indicates choosing to acquire an integration node dominates the conditions experienced during the war. There is, at most, a 16 percent increase in warfighting military utility from the Gulf War level if *any* integration center is acquired.

Case 2: Here, the space segment of the IMSIM model was evaluated by incorporating the segment's probabilistic distributions as described in chapter 3. The node and cost segments of the model are kept at their perfect levels, 1 and 0 respectively. The space segment *only* dictates the choice made by the DPL decision model. The effect on military utility of the space segment variables was ascertained from this case run. The decision to acquire *both* a CONUS and a theater integration center, Figure 5.3, dominates the other two choices — cost and node status are not considered, remember. This result is

expected since both centers have good attributes which override the bad attributes of the other. Having both makes available to the theater warfighter all the best attributes of each without any of the bad. What is interesting is acquiring a theater center and both are so close; these two clearly dominate the choice to acquire a CONUS based center. The improvements in timely and responsive data dissemination of space based imagery provided by a theater based center provide higher utility. There are a few areas where a CONUS center's capabilities improve over the theater, therefore acquiring both dominates all other choices when cost is of no interest.

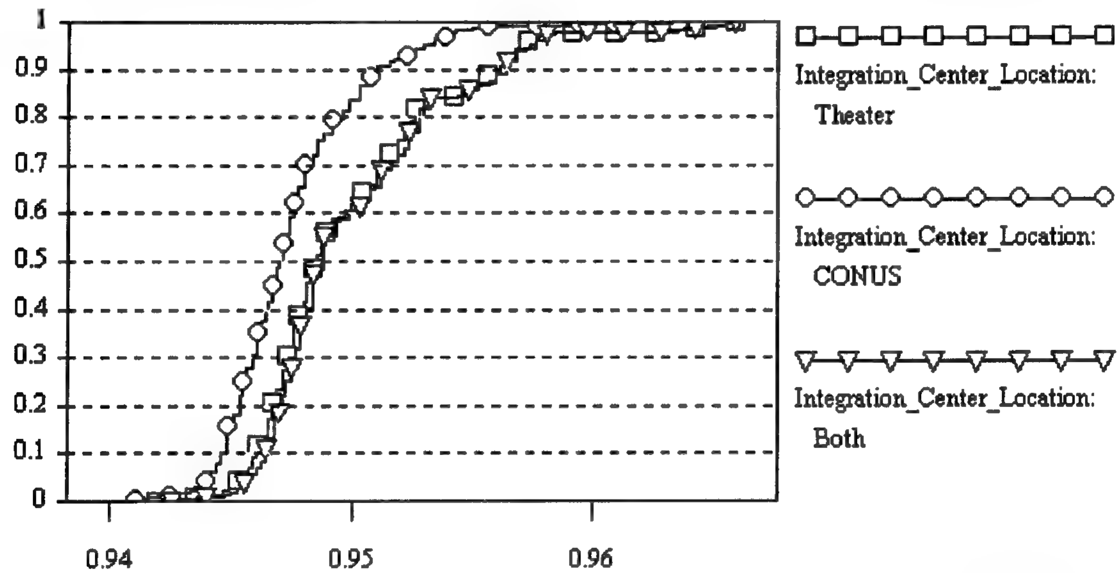


Figure 5.3: Case 2 IMSIM run result for probabilistic space segment.

Case 3: In case 3, the space and node segments of the IMSIM model were probabilistic. The cost segment was kept ideal at 0. Based on the military expected utility derived from the DPL simulation — without regard to cost again — choosing between the integration centers was not feasible over any other. The integration node status variable changes the utility given, as expected, the node status of a CONUS center was assumed to be perfect while the other two choices had considered possible degradation.

Acquisition Choice	*Expected Value*
Theater	0.9470
Conus	**0.9475**
Both	0.9472

The cumulative distribution function, Figure 5.4, for case 3 shows no dominance between any of the choices. This result indicates the node status variable reduces the effect the space segment has on the acquisition decision.

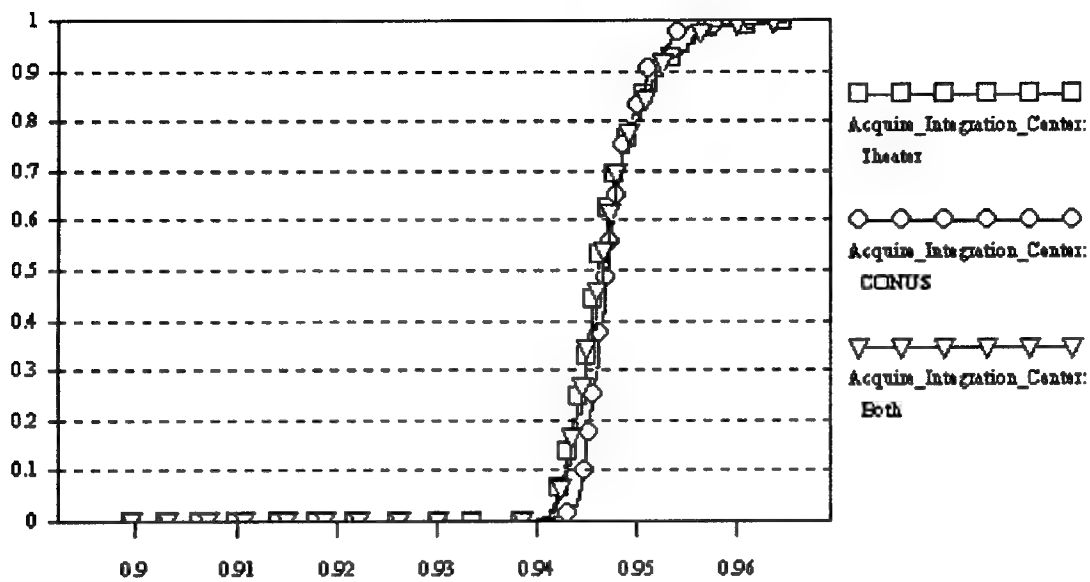


Figure 5.4: Case 3 IMSIM run result for probabilistic space and integration center status segments.

Case 4: In the final case evaluated, all three segments were included. Cost was weighted at 0.4 compared to military utility at 0.6. Assuming the theater integration center is cheaper than a CONUS center, factoring in cost overrides all of the other previous variables. A theater center is the dominant choice when including all segments, especially cost (see Figure 5.5). A rainbow diagram, Figure 5.6, of IMSIM's cost weight factor concludes there are decision changes only at the extremes, near 0 or 1. Of the three segments, cost drives the entire decision as to acquiring which center choice.

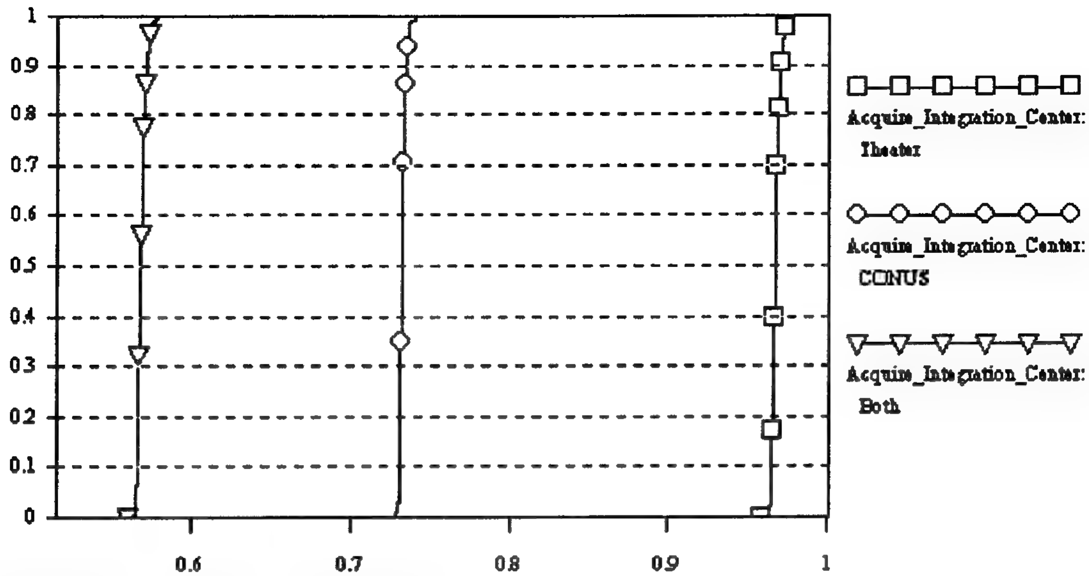


Figure 5.5: Case 4 probabilistic space and integration center status and weighted cost segments IMSIM run result.

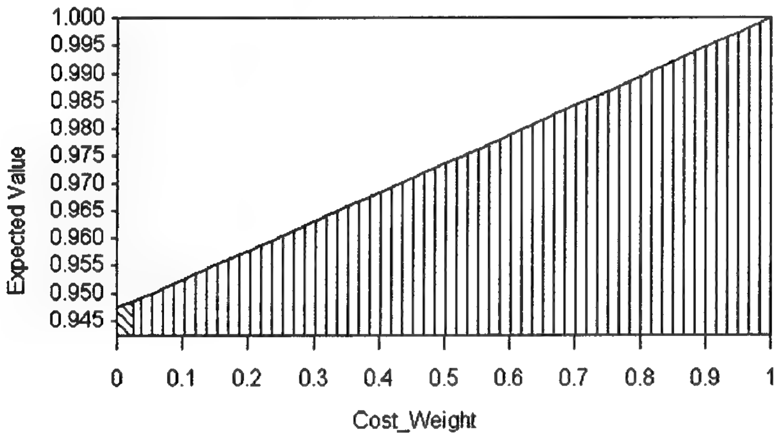


Figure 5.6: Rainbow diagram of cost weight within the IMSIM model.

5.1.3 Summary. The assumptions made within the node status and cost segments of the IMSIM model determine the preferred alternative. Adjusting the offensive weight factor to the combined IMSIM and TACSIM II models accounting for space, node status, and air combat factors (see the rainbow diagram shown in Figure 5.7) has a significant effect on the IMSIM model's decision outcome pertaining to deployment of a theater center. As the importance of using the data for offensive purposes increases — the offensive weight factor increases — the expected value of the integration center also decreases. When the offensive weight factor reaches approximately 0.5, there is a change in the decision as to deploy a theater center. When offensive weight is less than

0.5, the DPL model determines not deploying to a theater conflict as the most effective outcome. When offensive considerations increase, the offensive weight increases above 0.5, the decision is to deploy the theater center to the theater. With an integration center available, the EV decreases as offensive weight increases — same as the condition found earlier in section 5.1.1. Deploying an integration center seems to improve the offensive capacity of theater forces, given by the change is decision outcome as the offensive weight factor increases above 0.5.

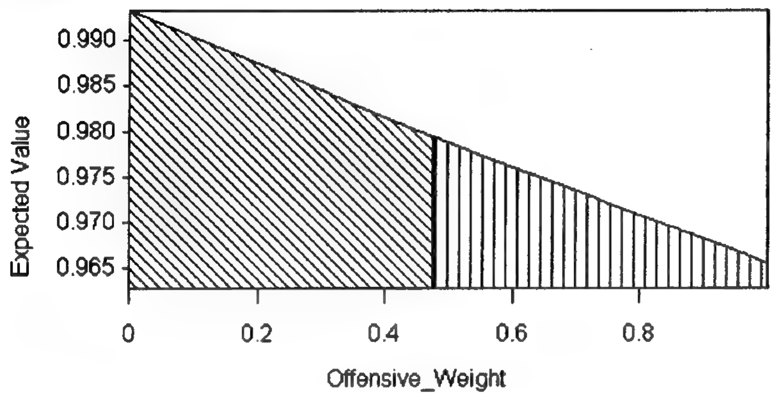


Figure 5.7: Rainbow diagram of offensive weight within the IMSIM model.

5.2 Sensitivity Analysis. Running a sensitivity analysis tornado diagram on the combined IMSIM and TACSIM II model provided the results as shown in Figure 5.8. Cost and offensive factors are the most sensitive variables within the model.

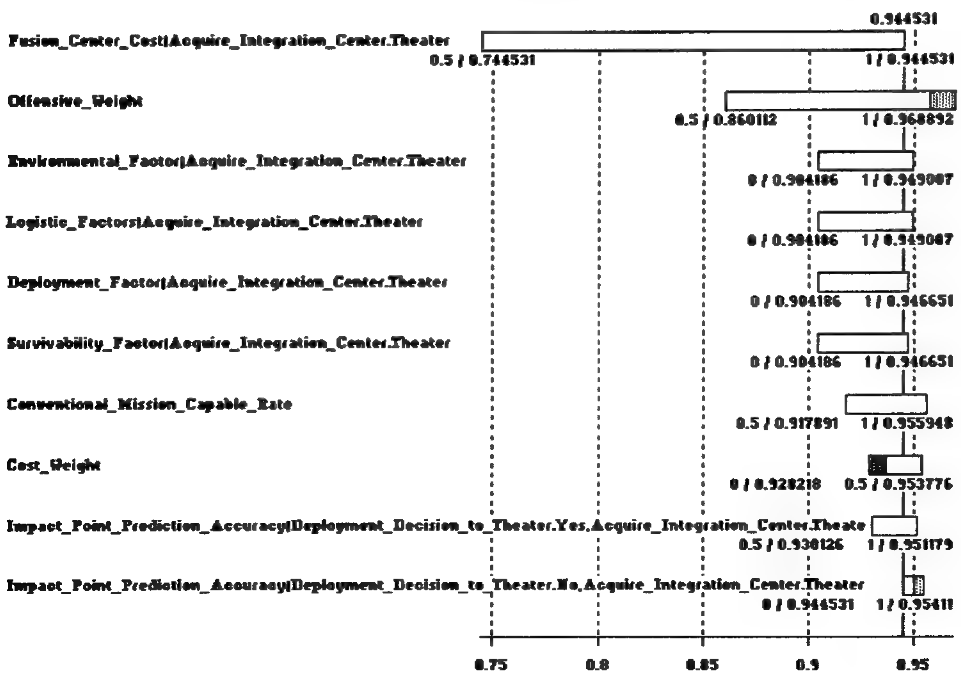


Figure 5.8: Tornado diagram sensitivity analysis of the IMSIM and TACSIM II model (see Appendix B for full tornado diagram of all variables).

5.3 Potential for Further Study. The IMSIM and TACSIM II models are a foundation for simulating the impact space based imagery has on a theater conflict. The models consider five individual threat scenarios for possible deployment. The capability to add scenarios and appropriate probabilities is one of the models' strengths. The simulation only considers on theater at a time, though. Current United States military strategy calls for the capability to deal with two, simultaneous regional contingencies [42]. The IMSIM and TACSIM II models need modification to incorporate this strategy. The next step in this simulation's development must be to consider two regional contingencies rather than one at a time.

Another significant area yet to be examined is the effects on air combat planning and execution of battle damage assessment (BDA) imagery. A first step would be adding an uncertainty node within the IMSIM model, called imagery assessment, and determining it's relationships with the TACSIM II model. When considering BDA in the IMSIM and TACSIM II, assuming a target hit is a target killed must be removed. Determining whether a target is killed is the role of BDA and must be modeled appropriately.

Imagery assessment is the effort to realistically and correctly evaluate surveillance data for information relevant to theater air combat planners. The reliability of surveillance imagery assessment is a function of the human factors and processing capabilities involved in evaluating the data for combat mission planning, execution, and resulting BDA. Folded into this reliability uncertainty node would be the relative effect human involvement has on the timeliness and accuracy of BDA determinations. During the Gulf War, the intelligence community in CONUS underestimated battle damage by between 50 and 75 percent for most targets whereas CENTAF and CENTCOM underestimated battle damage by between 33 and 50 percent [17: 205]. The reasons for these differences must be examined since there may be other unknown reasons involved besides location where BDA was done. New and archived imagery must reach theater planners within a time margin, defined as the time between when data is requested until it is needed [32: 61], under the twelve hour ATO cycle. The timeliness of *archived* imagery data is not a function of integration center location, only the timeliness of new information depends on node location. These reliabilities could be modeled as beta distributions. The analyst and

processing capability resources available to a CONUS integration node are assumed to be greater than those available to a theater center, but the timeliness of a theater node is greater since the urgency to make a decision is more pressing. Since experience from the Gulf War shows theater planners' BDA estimations are more reliable, the reliability of theater imagery assessment may be greater than CONUS assessment.

The challenge in adding BDA to IMSIM is relating the imagery assessment node to the TACSIM II model. BDA imagery affects the proportion of standoff weapons used, target recognized, target engaged, fixed target killed, number of sorties, percent targets killed, military utility, and fusion center value nodes to varying degrees. The interrelationships between and the feedback loops generated by adding imagery assessment to the models need to be examined and incorporated. BDA is a significant support mechanism for better air combat planning and conserving people and material. Investigating its overall impact is important in measuring imagery's impact in combat operations.

Related to BDA is the consequential changes in overall direct and indirect costs of acquiring and operating an ISS center. In the IMSIM and TACSIM II models, only direct procurement and operational costs for the ISS centers were considered. Further research should incorporate indirect and other costs attributed to acquiring, operating, and using an ISS center and it's collected imagery data. These indirect costs, which could easily be translated in dollars, include but are not limited to: sorties saved, casualties reduced, reduction in air missions conducting BDA, cost to the enemy in men and materials lost, and potentially shorten the length of the war — a political bonus.

5.4 Contributions.

1. Identified and quantified the key force qualities of weather, warning, and surveillance imagery.
2. Identified and quantified the impacts of the force qualities on air combat planning and execution.
3. Identified and quantified the key qualities of an integration node located in theater.
4. Analyzed the benefits of an integration center and highlighted it's key variables.

Appendix A : Space System Descriptions

A-1 *Landsat.* Landsat is a civilian, operational multispectral imagery (MSI) system. The current Landsat constellation consists of three satellites — Landsat 4, 5, and 6. Both are in north to south sun-synchronous, near polar, 98.2° 705km orbits with 0945 local equatorial crossings. Coverage area is from 81°North to 81° South. Swath width is 185 kilometers, or 115 miles, and results in a full image scene of 185 x 170 km (115 x 105 mi). Resolution is 30m for the 6 band thematic mapper, 80m for the 4 band multispectral scanner, and 120m for the one band of thermal infrared. The resulting image has a resolution of 30m. Landsat 6, launched in early 1993, adds a 15m panchromatic, black and white capability, resulting in images with 15m resolution. Military applications include limited mission planning for route selection, mapping and charting, beach and landing zone analysis, and target and change detection — detection of any differences between an old and a recent image of the same region. Command and control, tasking of the sensors, and distribution of the imagery products are performed by the Earth Observation Satellite (EOSAT) Company under contract to the National Oceanographic and Atmospheric Administration (NOAA). Air Force Space Command (AFSPACECOM) is not involved with the current Landsat operations. Requests for imagery, via the official channels, must be made to the DMA. DMA in turn, contacts EOSAT, or if the image is over two years old and archived, the U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center in Souix Falls, SD. EOSAT controls the distribution of imagery data. There are 17 receiving stations located around the world, permitting direct downlink of data. A major drawback of this seemingly enhancing capability is that the raw data must be sent to EOSAT in the U.S. for data processing to produce MSI products. Average wait from time of request to having image in hand is two to three weeks if the image is archived, and up to two months if a new image is needed [32; 34; and 12:1-2].

A-2 *System Pour L'Observation de la Terre (SPOT).* SPOT is a French owned and operated MSI satellite. The current constellation consists of two satellites — SPOT 1 and 2.

Both satellites are in north to south sun-synchronous, near polar, 98.7°, 832km orbits with 1030 local equatorial crossings. Coverage area is from 81° North to 81° South. Swath width is 60km per sensor. When both sensors are in twin vertical mode — looking directly down at nadir — the swath width is 117km. Both satellites have off-nadir collection capability. Up to 80km (50 mi) wide swaths within plus or minus 27° [plus or minus 475km (295 mi)] off nadir are achievable. This capability provides for limited stereoscopic imagery. Full image scenes are normally 60 x 60km (37 x 37 mi) and any off-nadir taken images are processed to appear as a normal nadir image. Resolution is 20m for the High Resolution Visible (HRV) sensors when in the 3 band MSI mode, and 10m when filming panchromatic. The resulting processed images have 10m resolution. SPOT 3 will have the same capabilities as the previous two satellites. Military applications include mission planning for route selection, mapping and charting, beach and landing zone analysis, target and change detection, and bomb damage assessment (BDA). Command and control, tasking of the sensors, and distribution of the imagery products are under the control of SPOT Image Corporation based in Toulouse, France. Request for imagery can be made directly to SPOT Image Corporation or through a U.S. based office located in Reston, VA. Requests for imagery by government agencies must be made to the DMA. DMA in turn, contacts SPOT Image Corporation for both new or archived data. SPOT Image Corporation controls the distribution of imagery data. There are two main ground stations to receive recorded and 16 to receive real-time data only located around the world. Each station has data processing capability; each may have different standards of processing. All data is sent to Toulouse and archived in a standard format. Average wait from time of request to having image in hand is less than a week if the image is archived, and up to three weeks if a new image is needed. Under mission critical situations, optimal orbit conditions, and best case results, new images may be obtained in about 48 hours. [32; 34; and 12:1-2].

A-3 *Defense Meteorological Satellite Program (DMSP).* Weather information at the theater level must be provided to the theater air combat planners in near real time — under 8 hours to support ATO development — since weather is a major factor in determining the success or failure of tactical air, land, and sea missions. Timely weather information is

vital to the battle director in making effective tactical decisions [19:1-2]. To accomplish this mission, the US Air Force uses the Defense Meteorological Satellite Program (DMSP).

DMSP is an operational military system providing an enduring, survivable, and timely capability to collect and disseminate encrypted global, visible and IR cloud data and other specialized meteorological, oceanographic, and solar-geophysical data to support DoD forces world-wide. This support is through all levels of conflict and consistent with the survivability of the supported forces.

On average, two DMSP satellites, each carrying a battery of sensors to record atmospheric phenomena, are traveling in a sun-synchronous polar orbit covering the entire earth every 12 hours. One gathers meteorological data in the early morning and early evening, the other during the midday and mid-evening. The data collected by this system can be directly downlinked to special processing terminals or recorded and then transmitted to one of two command readout stations at Fairchild AFB, WA, or Loring AFB, MA. Information is then relayed via a leased Hughes Westar satellite to the AF Global Weather Central at Offutt AFB, NE, and the Fleet Numerical Weather Central at Monterey, CA [49:35-36]. Advanced Space Data Corporation advertises their transportable and rapidly deployable direct downlink terminals now available to receive processed DMSP data wherever military forces are sent — these were used during Desert Storm. Scanners onboard the satellites produce images in the 0.4 to 1.1μm, visible and near-IR band and the 8 to 13 μm, thermal IR band. System resolution is on the order of 3km. Sun-synchronous poloar orbits permit day and night global coverage. A unique capability of the DMSP scanner is nighttime visible band imaging. This comes about through the ability to *tune* the amplifiers of the system to obtain images under low illumination conditions. The system produces vivid images of phenomena such as urban light patterns.

DMSP supports theater air operations by providing weather data for mission planning in two modes: fine data at 1.5 nautical-mile resolution collected for only 20 minutes per satellite per orbit and smooth data at 3.0 nautical mile resolution under no collection limitations. Data provided includes: cloud cover for visual target acquisition, surface-to-air

(SAM) fire, etc.; vertical moisture, humidity, and temperature profiles provided through a procedure called sounding to support lock-on range for electro-optical (EO) weaponry; infrared visibility for aircraft landing and takeoff, mission ingress and egress, and visual and EO target acquisition; and inferred winds for weapons delivery. This information DMSP provides is also important for survivability of theater (tactical) forces during trans/post attack operations [32].

A-4 *National Oceanographic and Atmospheric Administration (NOAA).* NOAA is an operational civilian, near-polar — 98.9° inclination — sun-synchronous orbiting system of two satellites at 833km, called Television Infrared Orbiting System (TIROS). TIROS provides non-encrypted, 3 to 4 nautical mile resolution, visible and IR imagery and multi-altitude soundings for air temperature, humidity, and derived winds data. NOAA also conducts regional soil moisture analysis and monitor dust and sandstorms. This data is input directly to the AF's Global Weather Center (GWC) twice daily at 0930 and 1330 central time. For NOAA, because about half the earth is obscurred by clouds on any single day, a composite period of 7 days of data is normally used to produce global vegetation index maps. NOAA systems 6 through 12 have the Advanced Very High Resolution Radiometer (AVHRR). The even-numbered missions have daylight, 0730 north-to-south equatorial crossing times and the odd-numbered missions have nighttime, 0230 north-to-south equatorial crossing times. Coverage is acquired at a ground resolution of 1.1km at nadir with a swath width of 3000km. NOAA satellites provide daily visible and twice-daily thermal IR coverage. NOAA receives AVHRR data at full resolution and archives them in two different forms. Selected data are recorded at full resolution, referred to as local area coverage (LAC) data. All of the data are sampled down to a nominal resolution of 4km, referred to as global area coverage (GAC) data. Images and digital tapes are used operationally in a host of applications, including military. [32;12:1-2].

A-5 *Synchronous Meteorological Satellites (SMS)/Geostationary Operational Environmental Satellite (GOES).* GOES is a civilian operated, visible imagery system in geosynchronous orbit. The SMS/GOES program, like the other civilian meteorological

satellite programs, is a cooperative venture between NOAA and NASA and are part of a global network of meteorological satellites spaced about 70° longitude apart around the world. The system downlinks cloud coverage of a full disk — half of the earth's globe — at 7 nautical mile resolution. This data is input every 30 minutes directly to the AF's GWC in support of DoD's weather mission. [32]

GOES sees an entire hemispherical disk. The repeat frequency is therefore limited only by the time it takes to scan and relay an image. GOES images are generated twice an hour in a visible band and a thermal IR band. The visible band operates during daylight hours, and the IR band runs day and night. GOES images are by now very familiar to us all. They are distributed in near real time for use in local weather forecasting. [32]

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        id AA16063; Tue, 29 Nov 94 17:52:57 GMT
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Date: Tue, 29 Nov 94 17:52:55 GMT
To: brichard@afit.af.mil
Subject: Jenny (of course)
```

Dear Bryan,

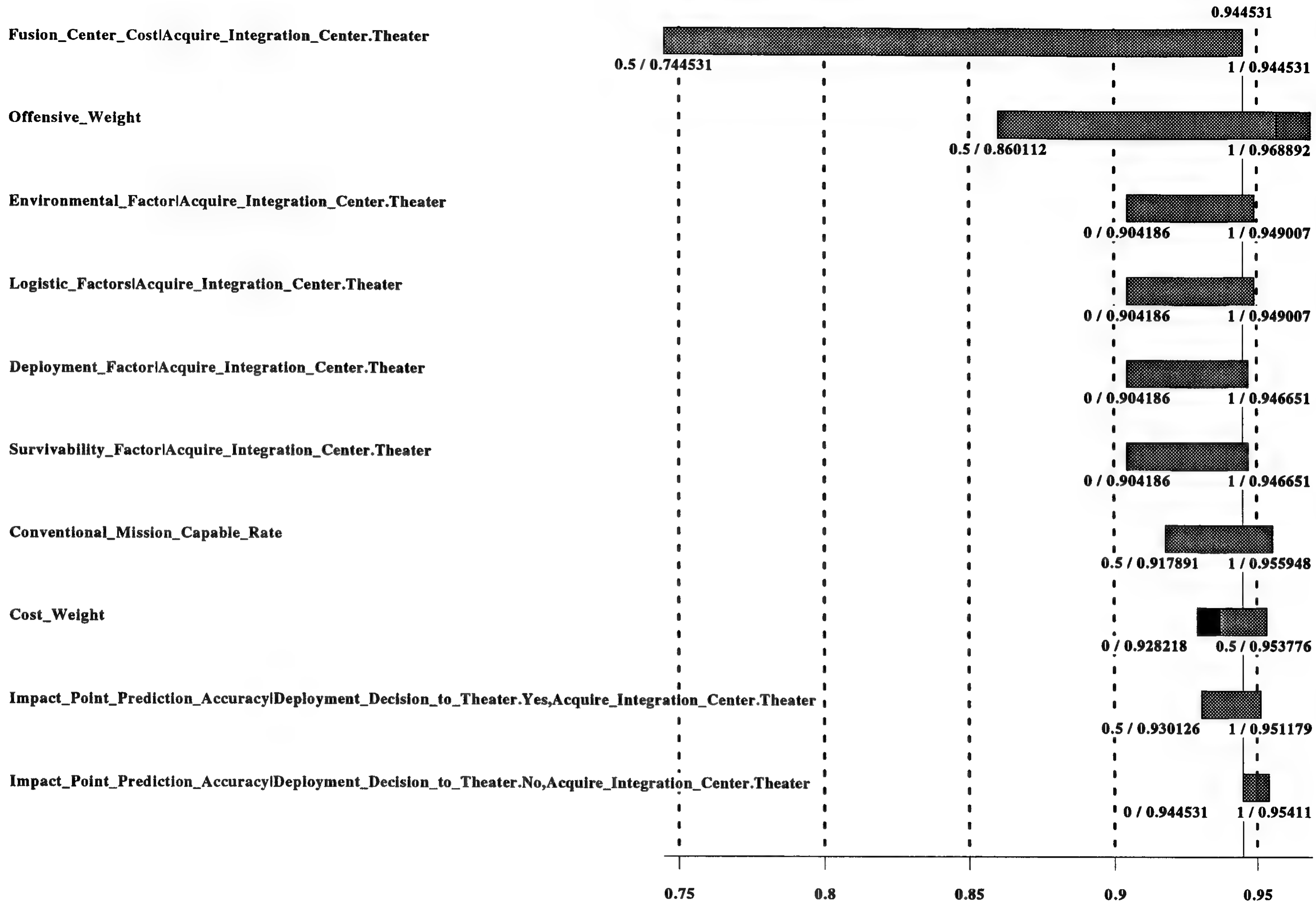
How are you? I just got a very interesting note from Jenny. Apparently she got a hold of Captain Hall (Her AOC) and he has looked into group job and wing jobs for her BUT he really wants her in the squadron next semester. He wants to work out her problems with the peers and not miss being in the squadron for 2 semesters in a row. He says that her Navy exchange is going to allow her to get a wing job next year with no problem. Anyway, she asked my opinion. Now she would be "jobless" next semester and a sitting duck for her peers that don't accept her. I don't think that she quite knows what to think, but will be contacting Major Tonneson and Col. Heinz for advice. I just hope this Cpt. Hall is not going to be sending HER for counseling again and having her suffer so like last semester.

Plus, if she doesn't let's say have a group or squadron position make her "look bad" for a wing or group job next year? I don't know about USAFA's ways, but "sitting out" one semester may look bad. What do you think about all of this - hope you understand what I'm trying to relay.

Thanks - write soon!

Peg

Appendix B : Sensitivity Analysis Tornado Diagram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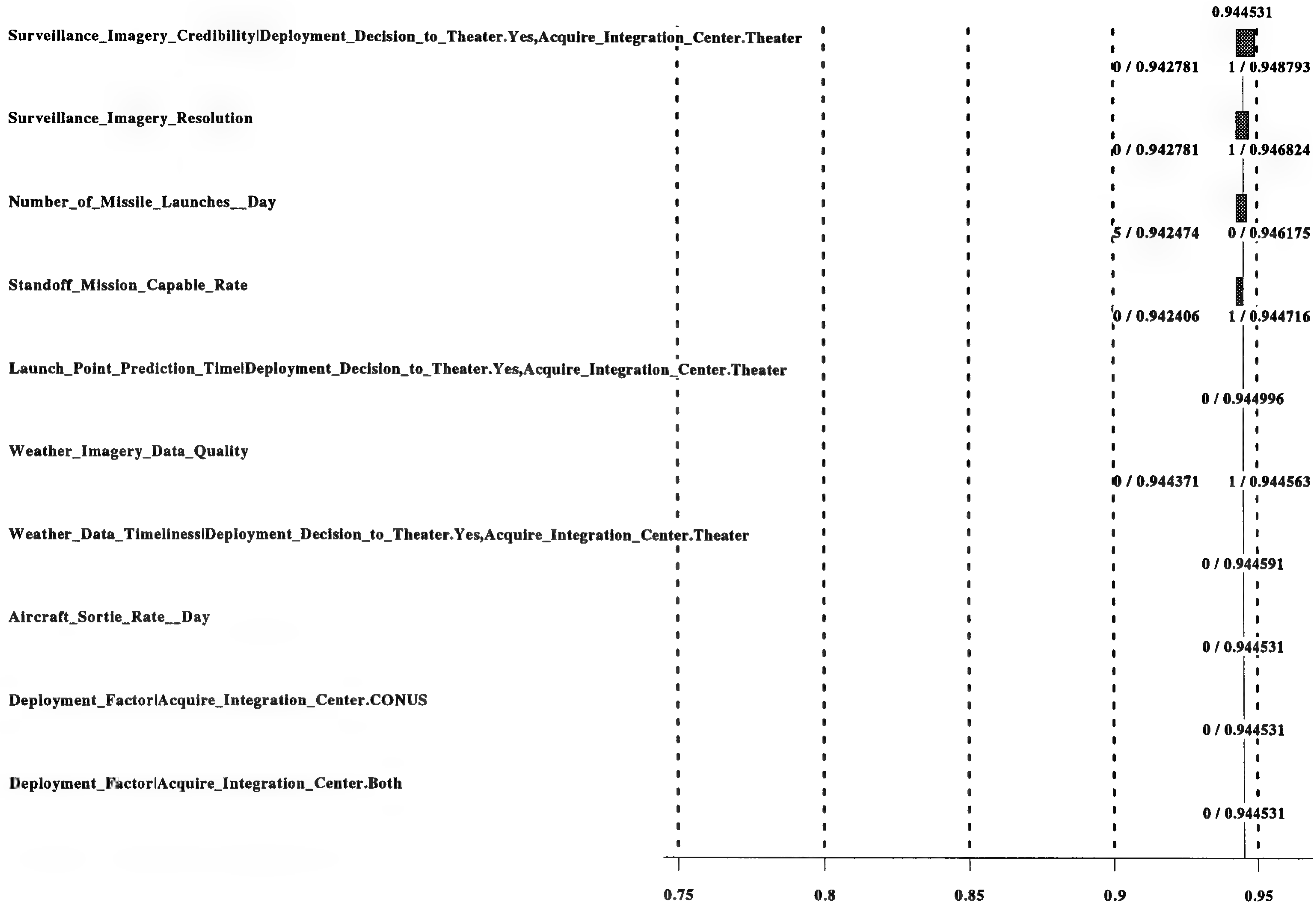
0.95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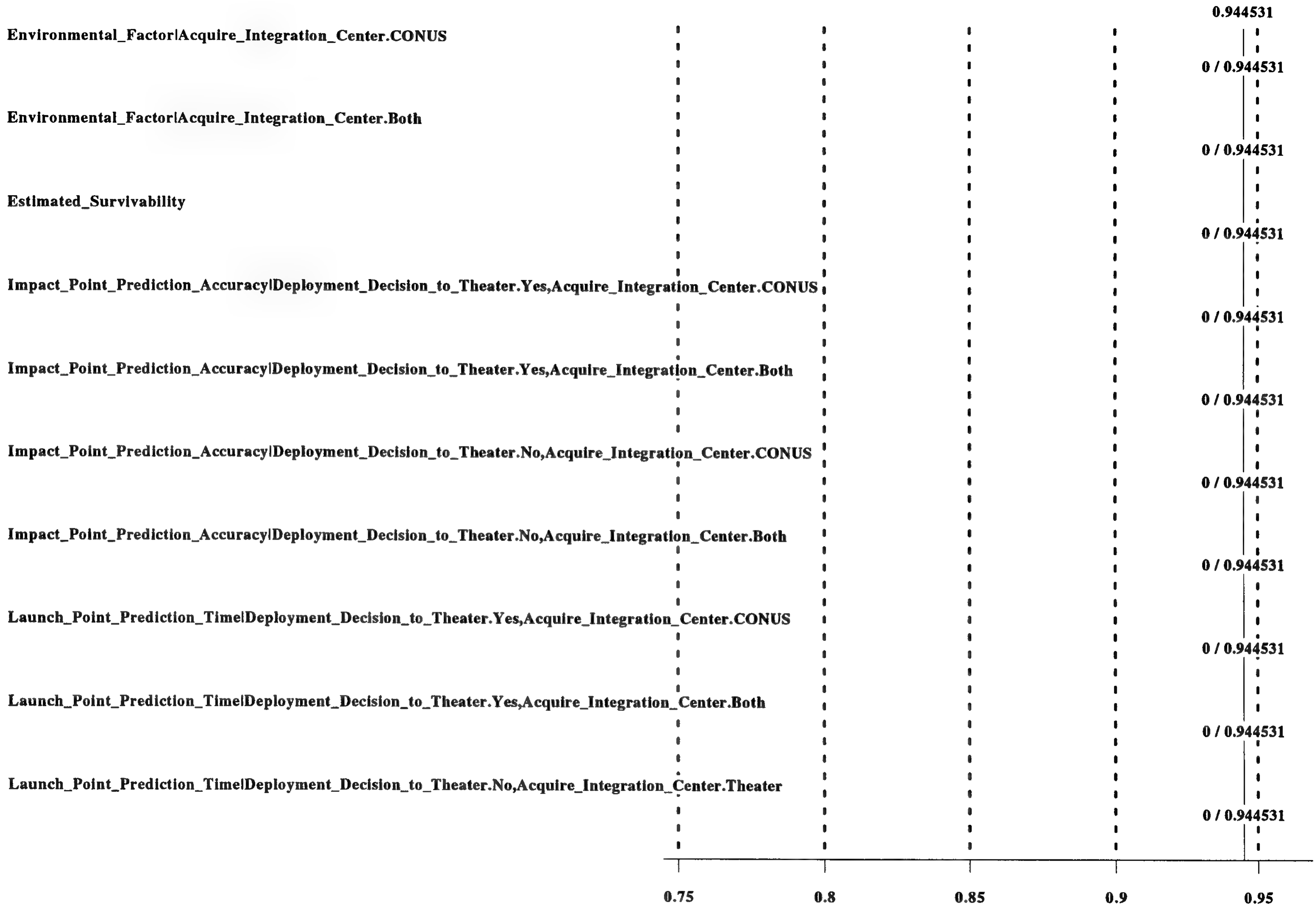
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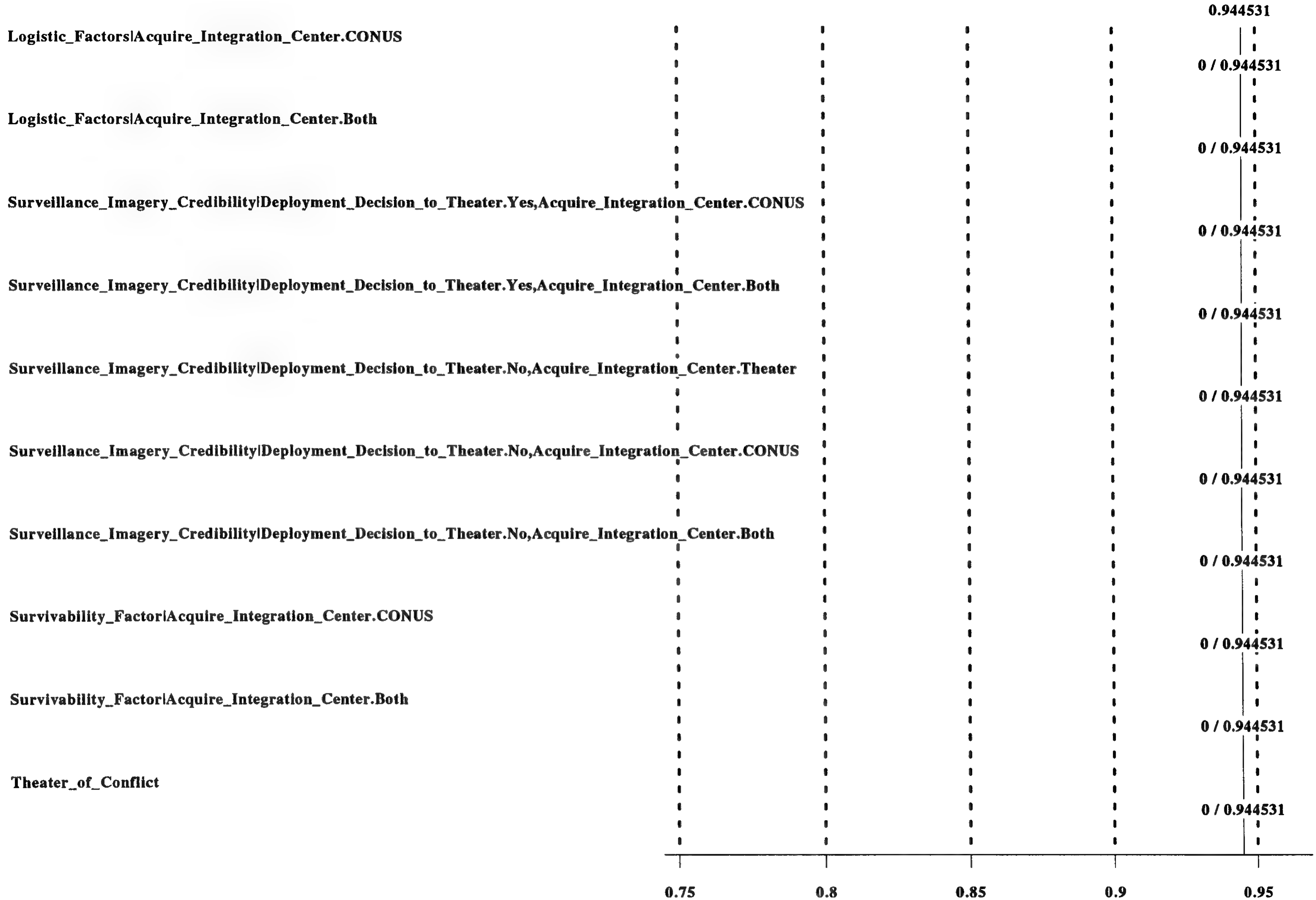
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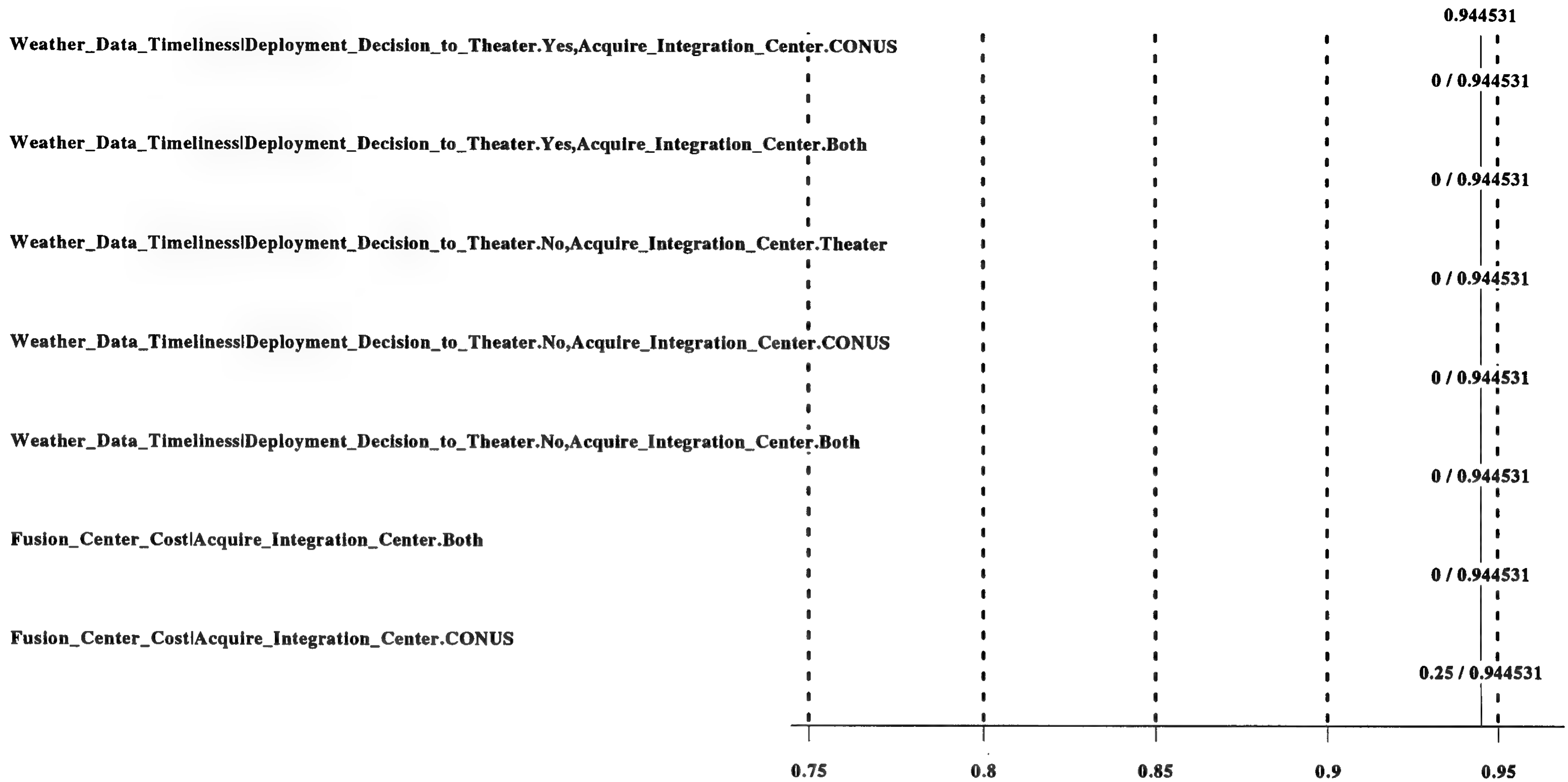
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Appendix C : Table of Acronyms

ACC	Air Combat Command
AF	Air Force
AFB	AF Base
AFR	AF Regulation
AFSATCOM	AF Satellite Communications
AFSCN	AF Satellite Control Network
AFSPC	AF Space Command
ATO	Air Tasking Order
AWACS	Airborne Warning and Control System
BDA	Battle Damage Assessment
CIS	Commonwealth of Independent States
CS	Constant Source
DoD	Department of Defense
DMA	Defense Mapping Agency
DMSP	Defense Meteorological Satellite Program
DPR	Data Preprocessor Relay
DSCS	Defense Satellite Communications System
DSP	Defense Satellite Program
EOSAT	Earth Observation Satellite
FLTSATCOM	Fleet Satellite Communications
FNOC	Fleet Numerical Oceanographic Center
FOC	Final Operational Capability
FOV	Field of View
GDN	Global Data Network
GOES	Geostationary Operational Environmental Satellite
GMS	Geosynchronous Meteorological Satellite
GPS	Global Positioning System
GWC	Global Weather Center
HQ	Headquarters
HRV	High Resolution Visible
IMPC	Integrated Mission Processing Center
IMSIM	Imagery Simulation
IR	Infrared

JCS	Joint Chiefs of Staff
JSTARS	Joint Surveillance Target Attack Radar System
JTIDS	Joint Tactical Information Distribution System
MAJCOM	Major Command
MSI	Multispectral Imagery
MSS	Mission Support System
NASA	National Aeronautic and Space Administration
NATO	North Atlantic Treaty Organization
NOAA	National Oceanographic and Atmospheric Administration
PGM	Precision Guided Munition
RES	Remote Earth Sensing
RF	Radio Frequency
RTS	Remote Tracking Station(s)
SMC	Space and Missile Division
SPOT	System Pour L'Observation de la Terre
TACSIM II	Tactical Air Combat Simulation II
TBM	Theater Battle Management
TIBS	Tactical Information Broadcast Service
TIROS	Television Infrared Orbitting System
TMD	Theater Missile Defense
TT&C	Telemetry, Tracking, and Control
TW/AA	Tactical Warning/Attack Assessment

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Vita

Captain Paul J. Helt was born in 1962 in Fargo, North Dakota. His family moved to East Grand Forks, Minnesota in 1969 where he spent his childhood. He was active in basketball, track, band, choir, student council, and many other extra-curricular activities throughout the secondary school years. After graduation from East Grand Forks Senior High School in East Grand Forks, Minnesota, he accepted an Air Force ROTC scholarship and entered North Dakota State University in Fargo, North Dakota, in 1981. In 1986 he graduated with a Electrical and Electronic Engineering and pre-Medicine degree, was commissioned, and entered active duty in Undergraduate Space Training, class one, at Lowry AFB Colorado in October, 1986. After graduation in February 1987, he began operational duties as a Deputy Missile Warning and Space Surveillance Crew Commander with the 20th Space Surveillance Squadron at Eglin AFB, Florida. In 1988 he transferred to the 20th Missile Warning Squadron, Cavalier AFB, North Dakota where he served as a combat crew commander and Chief of Training. While there, the unit, training shop, and operational crews were awarded as outstanding by a Standardization and Evaluation Team in April 1989. Captain Helt transferred to headquarters Air Force Space Command, Force Enhancement Division, Combat Support Division, in 1989, at Peterson AFB, Colorado. He met his wife in Colorado Springs and they were married in 1991. They had two children, Emily and Jacob, in 1991 and 1992. While at Space Command headquarters, Captain Helt was the command lead for the Global Theater Surveillance and the Space-Based Wide-Area Surveillance programs. He was command program manager for Project Eagle Dancer (a space-based radar demonstration), Project SHADOW (a transportable, theater-level, multi-satellite integrated mission processing and dissemination, command and control center), Project HAVE GAZE (a radar signal processing technology), Talon Shield, Multispectral Imagery/Remote Earth Sensing, Landsat, Long Dwell System, and the French SPOT programs. He developed warfighter requirements, operational concepts, schedules, test plans, and advocacy documents for all these programs and projects.

Captain Helt was a Distinguished Graduate from Squadron Officer School in 1993. Following headquarters duty, he was assigned to the Graduate School of Engineering, Air Force Institute of Technology (AFIT). Captain Helt and his wife divorced in 1994. Following graduation from AFIT in 1994, he is going to the imagery directorate in Rome Laboratory at Griffiss AFB, New York.

3023 Walnut Street
Grand Forks, ND 58201